Design Improvement and Performance Evaluation of an Improved Aluminum Biogas Burner for Injera Baking

Yidnkachew Dirsha Siwago

Design Improvement and Performance Evaluation of an Improved Aluminum Biogas Burner for Injera Baking

A Thesis Submitted to Department of Mechanical Engineering
School of Mechanical, Chemical and Material Engineering

Presented in Partial Fulfilment of the Requirements for the Degree of Master of Science in Thermal Engineering

Office of Graduate Studies

Adama Science and Technology University

May , 2024
Adama, Ethiopia

Design Improvement and Performance Evaluation of an Improved Aluminum Biogas Burner for Injera Baking

Yidnkachew Dirsha

Advisor: Dr. Dawit Gudeta

A Thesis Submitted to Department of Mechanical Engineering

School of Mechanical, Chemical and Material Engineering

Presented in Partial Fulfilment of the Requirements for the Degree of Master of

Science in Thermal Engineering

Office of Graduate Studies

Adama Science and Technology University

May ,2024

Adama, Ethiopia

DECLRATION

I hereby declare that this Master Thesis entitled **"Design Improvement and Performance Evaluation of an Improved Aluminum Biogas Burner for Injera Baking"** is my original work. That is, it has not been submitted for the award of any academic degree, diploma, or certificate in any other university.All sources of materials that are used for this thesis have been duly acknowledged through citation.

Yidnkachew Dirsha		
Name of Student	Signature	Date

RECOMMENDATION OF ADVISORS

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled **"Design Improvement and Performance Evaluation of an Improved Aluminum Biogas Burner for Injera Baking"** prepared under my guidance by Yidnkachew Dirsha Siwago, submitted in partial fulfillment of the requirements for the degree of Master of Science in Thermal Engineering. Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Dawit Gudeta		
Major -advisor	Signature	Date

APPROVAL

I, the advisor of the thesis entitled **"Design Improvement and Performance Evaluation of an Improved Aluminum Biogas Burner for Injera Baking"** and developed by Yidnkachew Dirsha Siwago, hereby certify that the recommendation and suggestions made by the board of examiners are appropriatelyincorporated into the final version of the thesis.

Dr. Dawit Gudeta		
Major -advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Yidnkachew Dirsha Siwago have read and evaluated the thesis entitled "**Design Improvement and Performance Evaluation of an Improved Aluminum Biogas Burner for Injera Baking"** and examined the candidate during open defense.This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirementof the degree of Master of Science in Thermal Engineering.

Chairperson	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

ACKNOWLEDGMENT

First and foremost, I would love to give my thanks to the almighty God for his presence in my life and keeping me from any endanger.

I sincerely appreciated my advisor, Dr Dawit Gudeta Gunjo, for his crucial guidance and inspiration helping me finish this works in its current forms. His guidance was crucial when it came to organizing and carrying out my long term objective. His motivation aspires me to do better in this work.

I want to express my deep gratitude to my instructor, Dr Gezahegne Habtamu and Dr Addisu Bekel, for their essential inspiration, constructive criticism and encouragement during my academic carrier. Finally, I want to thank all of my parent, friend and classmate for their encouragement and contribution to my research, which have made my thesis more rewarding.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

BD	Biogas digester
AD	Anaerobic digestion
BB	Biogas burner
BT	Biogas technology
Hf	Flame height
Re	Reynold number
Gr	Grashoff's number
Pr	Prandtl number
η	Efficiency
Nu	Nusselt number
Ra	Rayleigh number
CH4	Methane
Pg	Gap between port
Qm	Biogas flow rate of mixture

ABSTARCT

A biogas operating burner is a device used to generate a flame to heat up the product. Biogas burners have received very little attention up to this point. The effective use of the energy produced will depend not only on the energy source but also on the final technology employed to heat the product. An improved aluminum biogas burner geometry is necessary for efficient utilization of the gas coming from the biogas digester. Two problems uneven heat distribution and longer heating times associated with burner geometry pushed me to prepare such a design. The goal of this study is to improve the heat distribution throughout the baking pan and thermal efficiency of biogas burners. As a result, the baking pan will receive an even heat distribution with low emissions. The controlled cooking testing method was used to conduct the experiment. In this research work, design and performance evaluation an improved aluminum biogas injera baking burner was carried out. The performance of the newly designed biogas injera baking stove was evaluated by taking into account several key criteria during the experimental test cooking period, including temperature distribution, thermal efficiency, cooking time, and biogas consumption. As per the experimental test results, the newly developed biogas injera baking stove consumed 1.7 litters and took 1.57 minute to bake a single injera which is less compared with the previously developed biogas fuled burner which consume 2.5 litter and took 1.7 minute to bake a single injera. The newly developed injera baking burner using biogas had a thermal efficiency of 52.5 %. In comparison to the old stove, which had thermal efficiency 51 % of 8mbar operating pressure the newly developed biogas injera baking stove demonstrated a notable reduction in terms of thermal efficiency, the amount of biogas consumed, and the amount of time required for cooking.

Keywords: *Injera; Burner geometry; Biogas cooking stove, Biogas burner;*

CHAPTER ONE

1. BACKGROUND OF STUDY

1.1. Introduction

The number of people in the world using traditional biomass energy is 2.7 billion (IEA, 2015). In Ethiopia, 95 % of the population relies on the use of traditional biomass for cooking application (IEA, 2015) among which 50 % of the energy is used to bake injera traditional pan cake like bread. Due to the low efficiency of injera baking biomass stoves, large amounts of firewood are used, resulting in high indoor air pollution, greenhouse gas emission and rampant deforestation. The attempts to improve the injera baking stove resulted in incremental change in efficiency and reduction in emission of pollutants without major breakthrough.

Most of the people living in Ethiopia bake injera using biomass on open-fire stoves. The inefficient open-fire stove consumes large amounts of firewood and produces high indoor air pollution and CO2 emission. A three-stone-stove or a three-stand-stove is where three stones with a similar size are made from clay. The three stones are placed in a triangle to support or carry the baking pan with a diameter of 52 cm and thickness of 20 cm on average. Then, firewood is inserted into the openings between the stands for burning. While burning is taking place below the pan, injera is baked on it. In the process, 90 % of the energy supplied is lost to the environment. Moreover, the cook and her child is exposed to large amounts of CO and PM which is above the WHO standard set for safe cooking (Adem & Ambie, 2017).

Injera is made from teff flour which is mixed with water and allowed to ferment by adding left over batter from the previous baking session as a starter. When it is ready, fire will be lit from the bottom of the clay pan for biomass stoves and in the case of electric injera baking stove resistors will be turned on. When the pan's temperature reached around 200 °C, the dough will be poured into the baking pan. The viscosity allows it to be poured into the baking pan rather than rolling out. Finally, the baked injera will be removed from the baking pan. The majority of Ethiopians still bake injera using three-stone fire. Starting from1980s efforts have been made to improve biomass injera baking stoves and introduce electric injera baking stoves for urban dwellers (Yirgu et al., 2017).

Figure 1.1 Traditional three stone biomass injera baking stove (Tariku, 2020)

Renewable energy could provide the much desired sustainable rural revitalization in most developing countries. It is an ideal alternative because it could be a less expensive option for low income communities. An ideal renewable energy source is one which is locally available, affordable and can be easily used and managed by local communities. Biogas is one of a number of technologies that offers the technical possibility of decentralized approaches to the provision of modern energy services using resources such as; cow dung, human waste and agricultural residues to produce energy. It can be used for heat and electricity production and the digester residue can be recycled to agriculture as a secondary fertilizer. Biogas plant is relatively simple, economical, and can operate from small to large scales in urban and rural locations. In this regard, many African governments have realized that renewable energies could play a very important role in supplementing other existing energy sources.

Biogas is a clean-burning, "green" fuel used for heating and cooking, transport and power generation. Biogas usually contains about 55-65% methane, 30-35% carbon dioxide, and traces of hydrogen, nitrogen and other impurities. Biogas typically refers to a gas produced by the biological breakdown of organic matter such as dead plant, animal material, human faces, and kitchen waste in the absence of oxygen. Biogas can be used as a fuel in any country for any heating purpose, such as cooking, electricity and when compressed like natural gas can be used as vehicle fuel to power motor vehicles (Biogas & Engines, 2011). Biogas is a renewable fuel, so it qualifies for sustainable energy subsidies in some parts of the world. Biogas can also be cleaned and upgraded to natural gas standards when it becomes bio methane (G. Mohammed, 2015).

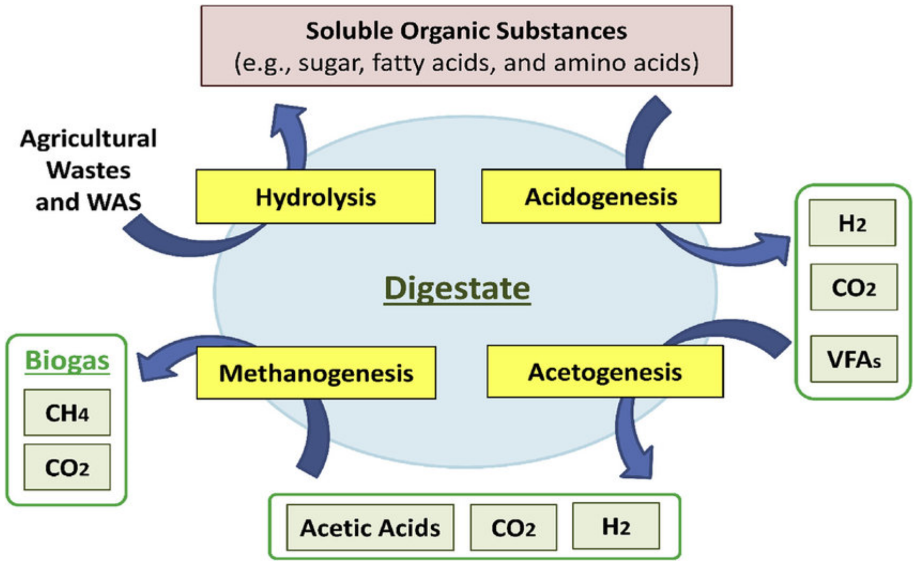


Figure 1.2 Methane gas production steps (G. Mohammed, 2015)

Because of the burner's low efficiency, the majority of the energy produced from various sources is wasted. This design is considered as a solution to such issue. Wide scale use of biogas is hindered by the low efficiency of biogas burners. Locally made burners cause problems for home biogas users, including heat loss and excessive gas consumption that affect the cooking process as a whole. With this in mind, the goal of this project is to developed and improve the performance of a locally produced an improved aluminum biogas burner. As a result, the cooking pot will receive an even distribution of heat and the fuel flow through the hose will be constant.

1.1.1. Biogas Technology Development in Ethiopia

Before the 1990s

In Ethiopia, during the early years of implementation of biogas technology, there was no focus on small scale domestic biogas, rather, institutional and large-scale digesters were deployed for introducing and demonstrating the technology. Biogas was first introduced in Ethiopia by Ambo Agricultural College around 1966 to supply the energy for welding agricultural tools. In the 1970's most of the biogas plants installed were floating drum systems and built by the then Ethiopian National Energy Committee (ENEC). For instance, the Food and Agriculture Organization (FAO) had demonstrated two biogas plants as a pilot project to promote the technology. reported that before the standardized SINIDU model was implemented by the National biogas program of Ethiopia, different biogas models have been installed in Ethiopia including Indian floating drum, Chinese fixed dome, CAMARTECH, Deenbhandhu, Polyethylene, and LUPO fixed dome type (G. Mohammed, 2015).

From 1990-2009

In 1991 it has been reported that 9 different institutions/organizations had constructed 103 biogas plants. In early 2000 around 360 biogas digesters were implemented with the majority of household type digesters and institutional type in a small amount. In all, the total number of domestic biogas plants installed in Ethiopia until the introduction of NBPE I was estimated to be from 600 to 700 [10]. Those biogas plants installed in the 1990s were mostly fully subsidized especially by the support of government and World Vision Ethiopia only the household contributed labor costs by digging bits which undermines ownership, of course, the cost of few plants installed by GTZ were covered by households [10]. In another report out of 103 biogas plants installed in 1991 almost all plants were not functional due to the installations were done without farmer's interest, but rather with a political motive, and poor Gas management (G. Mohammed, 2015).

Between 1999 and 2002, Christopher Kellner, a German biogas expert, built 60 fixed-dome biogas plants by providing technical advice without offering financial support to the household [10]. The types of digesters installed by Mr. kellener were a Chinese fixed dome type digester which is named LUPO design with a small modification of the fixed dome. Furthermore, since 2000, a local NGO called LEM-Ethiopia started an awareness and promotion program with latrine-fed biogas digester in schools and households in four regions of the country and installed from 22 - 25 biogas digesters. In 2006 experts from Ethiopian rural development and promotion center (ERDPC) and SNV conducted the feasibility study to determine the biogas potential in four regions of the country such as Amhara, Oromia, SNNPR, and Tigray, then the National Biogas Program of Ethiopia (NBPE I) had been initiated (G. Mohammed, 2015).

1.1.1.1. National Biogas Program of Ethiopia (NBPE)

Phase I (2009-2013)

In the Growth and Transformation Plan (GTP I) from 2011-2015, the government had launched a five-year project plan to install 3,400 biogas plants in Tigray, thus actually 3000 plants were successfully installed. Besides, it has been again planned to install 7000 biogas plants at the end of GTP II (GTP-

II; 2016-2020). From 2009 to 2015 more than 3,600 biogas plants were installed in the Tigray region by the national biogas program of Ethiopia. The federal and regional governments and Africa biogas partnership program subsidized 50 percent of the biogas plant installation cost and SNV subsidizes technical support and appliances (lamp, stove, iron bar, gas hose, and cement) that are crucial for the proper functioning of the biogas plant. Furthermore, the rest would be covered by the biogas adopters by arranging loan opportunities with Micro Finance (G. Mohammed, 2015).

The National Domestic Biogas Program (NBPE) was launched to increase the dissemination of domestic household biogas plants in Ethiopia. The first phase of the NBPE was completed at the end of 2013 in which 50% of the plants are expected to include a toilet attachment [13], and 58% of the 14,000 initially targeted biogas plants were built [14]. However, Official sources have also stated that 8063 biogas plants were built during this phase and distributed in four regions of the country as follows: 2480, 1992, 1892, and 1699 biogas plants in Oromia, Tigray, Amhara, and Southern Nation, Nationalities, and People Region respectively.

During NBPE I the installed digesters functionality rate was indicated by about 76% while 6% report biogas functionality with minor problems; 2% with major problems and 16% not functioning at the targeted 95% functionality rate [15]. Also, it was reported that more than 1700 individual masons for constructing digester had been trained and about 84 Biogas Construction Enterprises registered which 24 were active as of the end of 2014(G. Mohammed, 2015).

1.1.1.2. National Biogas Program of Ethiopia (NBPE)

Phase II (2014-2017)

NBPE had started the second phase of implementation at the beginning of 2014 and it extended until the end of the year 2017 [16] to install 18,000 household biogas digesters. The main objective of the second phase of NBPE was to develop a commercially viable domestic biogas sector, providing access to clean energy, increasing agricultural production by bio-slurry as a fertilizer, improving living conditions by reducing the workload and improving health the indoor air pollution, contributing to the reduction of greenhouse gas (GHG) emissions. According to the assessment conducted by as of May 2015, 11,461 bio-digesters had been installed in four regions; this is only 1% of the country’s conservatively estimated technical domestic biogas potential. In 2014 alone, a total of 1762 plants had been constructed summing up to 9825 plants constructed since NBPE I with 63% of all plants connected to the latrines. In 2016 national biogas program in Ethiopia had celebrated the successful implementation of 13000 biogas plants [19]. The SNV report also shows that by the end of 2016 NBPE had supported the installation of over 15,000 bio-digesters and also a total of 12,071 biogas digesters were built during the second phase. It has also been reported by that 18,082 biogas plants were installed from 2009-2017 during NBPE I and NBPE II (G. Mohammed, 2015).

1.1.1.3. NBPE + (2016-2020) Biogas Dissemination Scale-Up Program

NBPE+ is the continuous plan of NBPE phase II to install 35,000 digesters mainly for cooking and lighting in eight regions for 210,000 households [18]. During NBPE II the regions targeted to implement the bio digester are Tigray, Oromia, Amhara, and SNNP. For the first two years in 2016 and 2017 NBPE + started implementing bio digesters in four regions such as Somali, Afar, Gambela, and Benishangul Gumuz, and adds existing ones only after completion of NBPE II to avoid overlap and allow for building on results of NBPE II in existing regions and as of 2018 during NBPE + phase had installed 1934 biogas digesters. NBPE +, [18] reported that a total of 21,735 household size bio-digesters are constructed till June 2018, under the NBPE-I, NBPE-II, and NBPE+ in 8 regions of Ethiopia, and the same assessment has also indicated that 23,802 household size bio-digesters were installed as of April 2019 (Kanase-Patil et al., 2010).

Several scholars have made attempts and put their efforts forward to design and analyze biogas burners for Injera baking purposes. From those scholars, a few of them conducted their research on it. Mulugeta et al., 2017 performed research on a biogas Injera baking burner with a manifold external diameter of 170mm. The experiment and analysis results demonstrated that the burner was small and, therefore, insufficient for baking the Injera pieces of bread. Decker et al., 2018 conducted research on burner flame portholes. The burner consisted of rectangular flame portholes, which caused friction during air-fuel mixture flow, hence reducing flame stability. Orhorhoro et al., 2018 designed an improved biogas fuel stove because the existing burner had low efficiency. The study focused on the gap between flame portholes, mixing tube length, flame port diameter, and distance between the cooking pot and stove burner. After the analysis and improvement, the maximum efficiency obtained was 63.87%. Sukhwani et al., 2012 designed and conducted a performance evaluation of an improved biogas stove. In the analysis, the variation of burner flame, port diameter and the preheating of the biogas to increase its efficiency. The results showed an increased performance efficiency of 42.99%. This research intends to design and analyze an improved aluminum biogas burner to increase its potential because of its poor conventional burner design (Ferrer et al., 2011).

Types of Burner

There are various types of burners available in the market depending on applications.

Gas Burners:

- These burners are primarily designed to utilize natural gas or liquefied petroleum gas (LPG) as fuel and commonly used in industries requiring high-temperature applications, such as metalworking, glass manufacturing, and power generation (www.biogas burner classification., 2022).

Figure 1.3 Gas burner (www.biogas burner classification., 2022)

Oil Burners:

- Oil burners are designed to burn various types of liquid fuels, including heavy oils, light oils, and even waste oils. They find applications in industries like refining, petrochemicals, and food processing.
- Oil burners are known for their versatility and ability to provide consistent heat output over extended periods.
- Atomization of oil is carried out to fast vapor formation of liquid fuel (www.biogas classification, 2022).

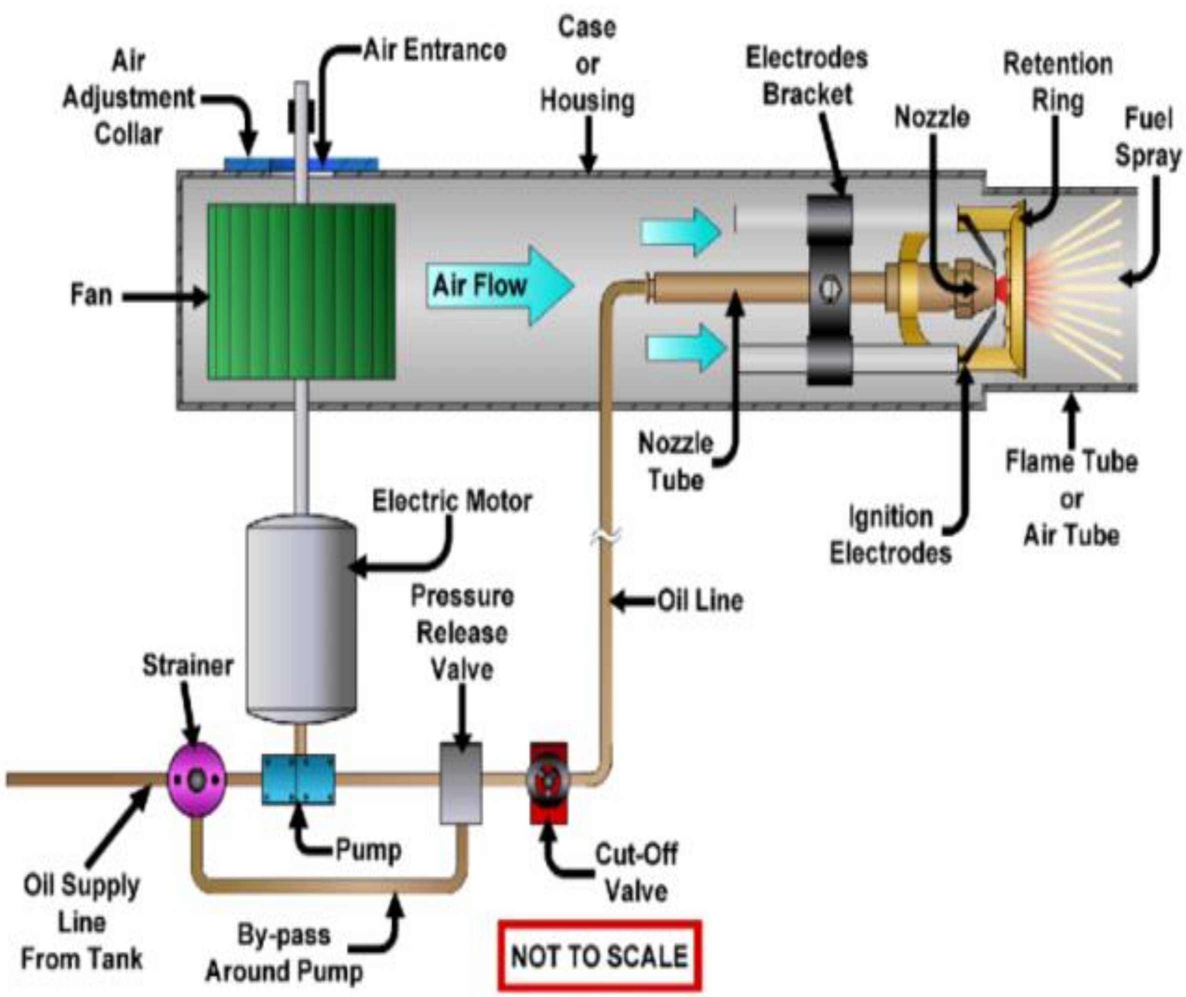


Figure1.4 Oil burner (www.biogas burner classification., 2022).

Dual-Fuel Burners:

- Dual-fuel burners offer the flexibility to operate on two different types of fuels, usually gas and oil.
- This versatility allows industries to adapt their fuel sources based on availability, cost, or emission regulations.
- Dual-fuel burners are commonly used in sectors with fluctuating fuel supplies or those requiring a backup fuel source [www.biogas burner classification, 2022].

Pulverized Coal Burners:

- PC burners are used in thermal power plants
- These burners are designed to burn pulverized coal, a finely ground coal powder that is blown into a combustion chamber.
- Pulverized coal burners are widely used in power plants, providing a cost-effective and efficient method for coal combustion (www.biogas classification, 2022).

Major Component Parts of Biogas Operating Burner

The biogas burner consists of several parts the one that is observed at the top of the burner is burner port that allows the flame to escape from it with the aid of jet or orifice and to heat the pan the other parts of the burner is sheet metal casing which surrounded it and hold the burner safely. The rest parts of the burner are the one that is made from aluminum allow everything is to happen on it.

Working Principle of Biogas Operating Burner

Most of the biogas burners follow the same working principle. When gas reaches a definite speed at the mitad, this speed is obtained by applying the given pressure from the biogas cylinder in a pipe of a definite diameter. With the aid of a jet or orifice at the inlet of the burner, the speed increased, producing a draft that sucks air into the pipe. This air called primary air and needed for combustion. Therefore, it must be properly mixed with the biogas in a preset stoichiometric ratio. This occurs by making the pipe have the required minimum diameter, which is in constant relation to the diameter of the jet. By widening the pipe further, the speed of the gas is reduced. This diffuser goes over to the burner head. The cone of the diffuser and the shape of the burner head are formed in such a way as to allow the gas pressure to equalize everywhere before the gas/air mixture leaves the burner through the orifices at a speed only slightly above the specific flame speed of biogas. For final combustion, the gas needs more oxygen, which is supplied by the surrounding air. This air is called secondary air.

1.2. Problem of Statement

In Ethiopia 95% of the population relies on biomass using for cooking application. Among this 50% of energy used for bake injera. Due to this a large amount of fire wood used which resulting high indoor air pollution and greenhouse gas emission. To prevent or minimize these problems and to address growing concerns, such a design is proposed. Problems associated with the existing biogas burner arise due to improper biogas burner geometry the problem related to burner geometry is that the dominant ones will cause non-uniform heat distribution throughout the baking pan. This will significantly affect the texture of the injera. In order to improve and solve such a problem, redesigning the existing burner geometry, such as the diameter of the flame port hole, the inter port distance, the manifold diameter, and the burner head height, is considered a viable option in this study. That is why such a design is proposed for injera baking application.

1.3. Research Question

- What design mechanism can be developed to reduce non uniform heat distribution through injera baking pan?
- Which operational parameter affect the burner efficiency negatively?
- What differ the improved aluminum biogas burner design from previously existing conventional biogas burner?

1.4. General Objective

The general objective of this study is to design and evaluate the performance of an improved aluminum biogas burner for Injera baking.

1.4.1. Specific Objective

- To design and fabricate injera baking burner
- To evaluate the performance of burner experimentally

1.5. Significance of Study

This research is very important in terms of its theoretical and practical contribution to existing science and the community that is mainly engaged in these activities. The theoretical parts of this research will lay the foundation for the academic support of existing biogas technology. The previous researcher emphasized more on biogas generation and using conventional burner designs. The findings of this research will have a positive impact on the advancement of biogas technology and will take innovation one-step ahead. This research will be beneficial in many ways and can be used as a basis and input for policymakers and energy efficiency regulatory bodies.

1.6. Expected Outcome

- Good biogas quality
- Energy efficient and better performance biogas burner
- Good thermal efficiency with evenly heat distribution and lesser heating time as compared to the previous conventional burner

1.7. Organization of Research Paper

This thesis paper comprises of six (6) chapter from chapter one (1) up to chapter six (6) are listed below:

Chapter One: consist of introduction of biogas energy its definition, detail about biogas burner, types of biogas burner and its working principle

Chapter Two: consists the literature review parts of the research paper explore previous research works on biogas burner works and identifies the gap observed on burner

Chapter Three: consists method and methodology parts of the paper it is mainly show the sampling techniques used to determine sample size of the population, the data collection method employ primary and secondary method and the final one analyzing the data gather using some software.

Chapter Four: consist of the analytical design of each parts of an improved aluminum biogas burner for injera baking.

Chapter Five: consists the experimental procedure and description the list experimental instruction we should follow while testing the performance of burner and detail description of it available in this portion of the paper.

Chapter Six: consists result and discussion parts of the paper in this part validation of numerical result and computation result taking place.

The last parts of the paper: consists of conclusion and future works in this based on the result obtained in the above we conclude about the test result and we put the recommendation the other to work on the gap leave in this portion of the paper. this is the last parts of the paper we put the reference we for all chapter.

1.8. Scope and Limitation

In this study, the following parameters, the design of the burner, and evaluated the performance of the aluminum biogas burner for injera baking. This study found a viable solution to the non-uniform heat distribution throughout the baking pan and the high fuel consumption of the burner by redesigning the existing geometry of the flame port and the inter port distance. The thermal efficiency and emissions of the newly designed and constructed burner were analyzed and tested. The sequence of this work is described as follows:

Activity One: First of all, determined the size of biogas digester of 10 m^3

Activity Two: the maximum gas pressure obtainable in the digester selected. The maximum operational pressure of biogas on a digester was 8000pa.

Activity Three: determine sizes of different parts injera baking biogas stove by Analytical method.

Activity Four: Selecting the materials for the injera baking biogas stove parts.

Activity Five: Selecting manufacturing methods.

Activity Six: Fabrication and assembling of biogas injera baking stove was done.

Activity seven: Experimentally tested the performance of newly developed biogas injera baking stove was done.

The followings are limitation of this study:

- Deformation and corrosion are two mechanical problems that can have a major impact on the operation of an aluminum burner. The thermocouple used to measure the temperature distribution of the combustion chamber unable to withstand the flame temperature which is released from the combustion chamber.

CHAPTER TWO

2. LITERATURE REVIEW

This chapter contains a number of literature reviews that are relevant to the study of biogas generation from different wastes and different deign of biogas burner and its performance such as, thermal efficiency and emission. biogas fueled burner is devices that use biogas gas as energy input and generate flame to heat up the product. People who live in rural areas and urban use this burner for different household application. Among those application injera baking is the major ones and energy intensive activities that is why most of the researcher focused on this area. Many researchers have worked tirelessly to improve the calorific value of the biogas generate from different wastes and thermal efficiency of burner. Now in this section, early and recent research efforts on improvement of injera baking stove is discussed.

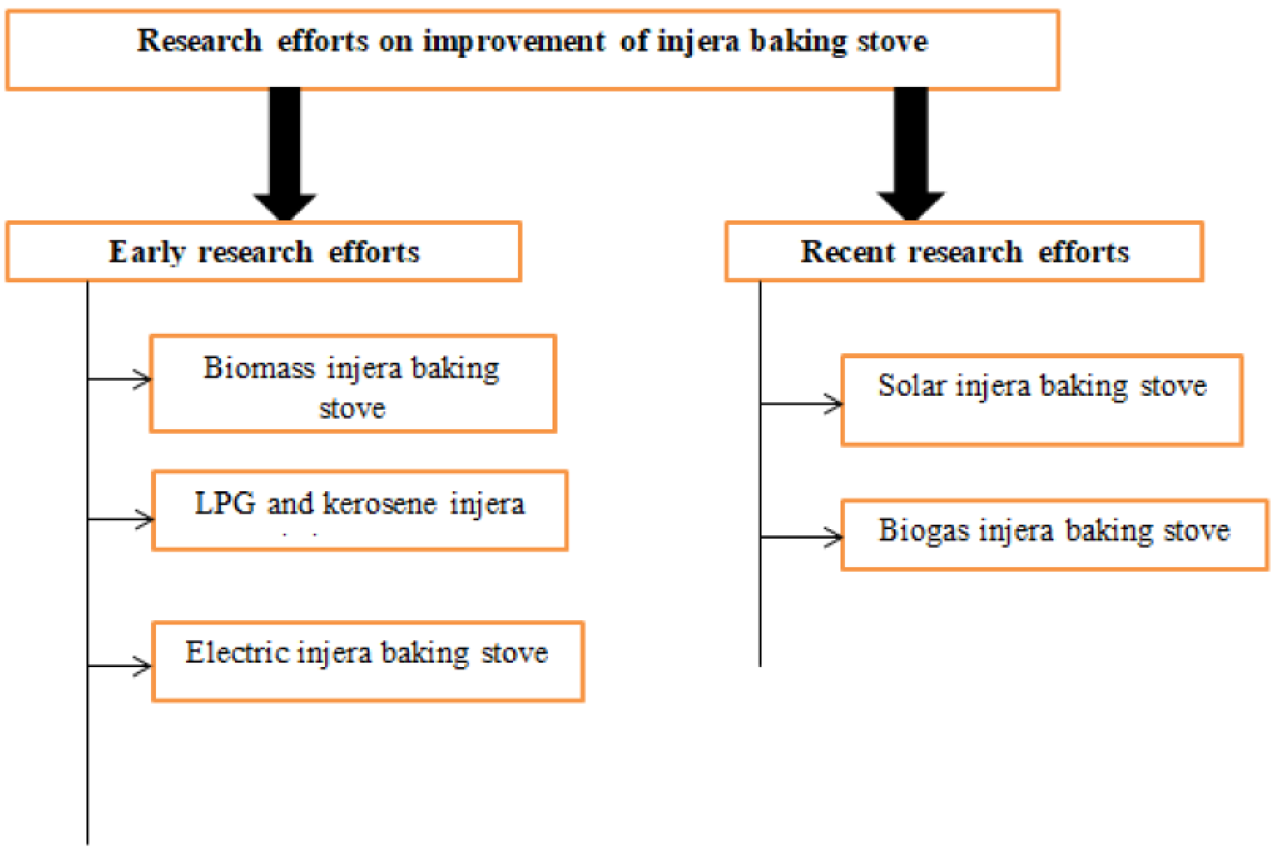


Figure 2.1 Research efforts to improve injera baking stoves(Mohammed et al., 2023)

The above figure 2.1 depicts the total amount of research efforts aimed at improving the injera baking stove. These efforts can be divided into two categories and examined in more detail: early and more recent attempts. Based on energy (fuel usage), such as biomass, kerosene, LPG, and electric injera baking stoves, early research improvement efforts might be categorized and discussed. On the other hand, current advancements in injera baking burner technology, including solar, electric and biogas models, should be explored.

2.1. Early Research Efforts

2.1.1. Biomass injera baking Stoves

The long-standing demand for efficient injera baking ovens wasn't addressed until government organizations laid the foundation in the 1980s. One of the first attempts was to make mud injera baking ovens at the Ministry of Education's Burayou Basic Technology Centre (BTC) in the early 1980s. It was called the "Burayou mud-stove." In 1981, the then-Ethiopian Science and Technology Commission (now the Ministry of Science and Technology of Ethiopia) hired a consultant to assess traditional closed stoves in certain regions of the country1981 (Ali , 1981).

The main objective of this study was to conduct a survey of the many types of stoves that are currently being used nationwide. The diameter of 60–65 cm and the thickness of less than 2.5 cm of 113 clay stoves, or mitad, were measured and subsequently surveyed. There were discovered to be 109 distinct stove kinds; these will be further investigated. Following their classification into 20 stove types according to their commonalities, six stoves were eventually selected for further testing. In the assessment, stove a pit-style stove was shown to be the most efficient stove. Chid, or teff straw, and clay were the building materials for this furnace. Every part of the stove was made of clay and chid, hence the name "Burayou mud-stove" (Ali , 1981)

In 1986, the Ambo team modified the Burayou mud-stove and came up with the Ambo mud-stove used for injera baking (ITDG-GTZ, 1991). In the early 1990s, a team of experts at the then Ethiopian Energy Authority with consultants from abroad started a survey to make a starting point for the development of injera baking stove in the country. The assessment made throughout the country revealed that the Burayou, Ambo and Tigrian mud stoves were the more efficient stoves at the time of the study, in 1991. When tests were conducted on the above mentioned three injera baking mud stoves, the variation in performance was associated with thickness and seasoning skill of the mitad.

Enclosed traditional injera baking stoves are commonly used in the northern part of Ethiopia, mostly in Tigray (Tigray National Regional State) and Wollo (a province in Amhara National Regional State). They are named after the area where they are most popular in Tigray and hence, it is commonly referred as Tigrian stove. These stoves, unlike three-stone injera baking stoves, are permanently built on the ground or on a raised platform made up of mud and stones. Users build the stove according to one's estimate of dimensions. In some places, the height of the stove varies from 28 to 40 cm with one or two smoke outlets. A typical Tigrian injera baking stove has usually two smoke outlets and a height of about 35 cm. The efficiency of a well-built enclosed Tigrian injera baking stove is about 12% (Tim, 1991). Compared to the three stone open fire injera baking stove, it consumes less fuel, and is easier to use and protects from burns.

Together with the Rural Technology Promotion Centre in Mekele, GIZ (formerly GTZ) developed the Tehesh injera baking stove. Enhancing the current Tigrian injera baking stove gave rise to the concept for Tehesh. Tehesh injera baking stove, as seen in Fig. 2c. Soil, rocks, and straw are the basic ingredients required to make Tehesh. To make the mud stick better, a small amount of fresh manure is combined with it. Both inside and outside, this mixture is spread over the stone that is built vertically. By sandwiching it between the stove's outside and interior walls and beneath the combustion chamber, straw is utilized as insulation (RTPC, 1998).

Sodo injera baking stove is made by the Rural Technology Promotion Center in Sodo. The name of the stove is taken from the place it was first designed. It is an enclosed stove made of 2 mm sheet metal. The Sodo injera stove can support mitad (stove) sizes between 54 and 56 cm. The total height of the stove is 42 cm. The combustion chamber is 60 cm in diameter and 15 cm in height. It has an ash-collecting box under the perforated metal grate (Fig. 2d). The controlled cooking test conducted by Sodo RTPC on a 45 cm diameter mitad shows that the average fuel wood consumption of the stove was 0.343 kg wood per injera (MoA /GTZ, 1999).

Tests were conducted on the Burayou, Ambo and Tigrian stoves, and Ambo was found to be the most efficient compared to the other two injera baking stoves, but the fuel consumption reduction was not satisfactory. Later on, important modifications were made and the team of experts came up with a mud injera baking stove which is efficient, and they named it ‘Mirt’, which means ‘best’ (Endale et al.,1992). Consequently, the mud structure of Mirt is changed into cement mortar mixture to build the fire chamber enclosure as shown in Fig. 2e. And this stove is widely promoted by the GIZ-Energy

Bureau Office in Ethiopia and named Mirt. The specific fuel consumption of Mirt stove has been determined by a number of researchers and developers. The average specific fuel consumption of Mirt stove is 535 g of wood per kg of injera (Table 2).

The Mirt stove was evaluated at the Aprovecho Research Centre. 6407 g of fuel was utilized in the test, which used the water boiling test process with a 35.8-minute boiling time. 192 g of CO and 5322 g of PM were recorded. 18% (time to boil), 81% (fuel use), 90% (CO), and 83% (PM) were reduced as a percentage due to the better design. The experimental alteration made to the Mirt stove is displayed in Fig (Hatfield et al., 2006).

Gonziye is the name of the second enhanced injera baking stove, which is constructed of clay (Fig 5). This enhanced multipurpose cooking stove may be used for preparing wot3 and baking injera as well as other cooking tasks like boiling water and brewing coffee. Gonziye injera baking stove's specific fuel consumption is 617 g/kg of injera (Anteneh, 2014).

Awramba, named for the Awramba settlement in Amhara Regional State, is the other upgraded injera baking stove. Since 1971, the community has used this injera baking stove for baking. Not only does this stove bake injera, but it also incorporates other cooking uses. Compared to the open-fire injera baking stove, it boasts a specific fuel consumption decrease of 35%. The Awramba injera baking stove can be used to simultaneously bake and cook injera, as demonstrated in Fig. 2h. (Walelign et al., 2013).

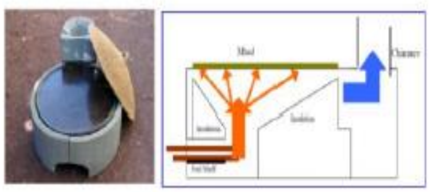
No.	Improved biomass injera baking stoves	
1.		3- Stone Biomass injera baking stove
2.		Tehesh biomass injera baking stove
3.		Mirt biomass injera baking stove
4.		Gonziye biomass injera baking stove
5.		Awramba biomass injera baking stove

Figure 2.2 Early research efforts(Mohammed et al., 2023)

2.2. Recent Research Efforts

Concerns about the environment, human health, and possible reduction in energy loss during injera baking have led to an increase in research on improving the efficiency of injera baking stoves in recent years. As shown in Fig. 4, the process used in recent studies starts with the optimization of a computational model to create a better injera baking thin plate made of ceramic or another material with experimental validation to minimize specific energy consumption. The second method uses thermic fluid and steam as working fluids to bake injera utilising solar energy.

The main goal of the numerical investigation was to determine whether numerical techniques could be applied to the performance indicators of electric injera baking ovens using the finite element method. Using a 2D transient Finite Element Method, the temperature distribution is measured during the baking of injera on both new ceramic plate and conventional clay plate. Both showed a reasonable heat-up and bake time throughout the test.

When compared to experimental results for various power sources and thermocouple temperatures, the numerical analysis showed very little inaccuracy. When the trial results using an 8 mm thick ceramic pan and a 20 mm thick clay pan on an electric injera baking stove were compared, it was found that the ceramic plate baking pan had a thermal efficiency of 66% and the clay baking pan had a thermal efficiency of 53%.

In a similar vein, the ceramic pan's thermal efficiency for baking 10–15 injera was 66-72%, whereas the clay pan's was 53-66%. The ceramic pan was made by the Ethiopian ceramics manufacturer Tabor Ceramic Plant. The outcomes of these studies' numerical computations cannot be directly compared to the effectiveness of electric injera baking stoves (Adem & Ambie, 2017).

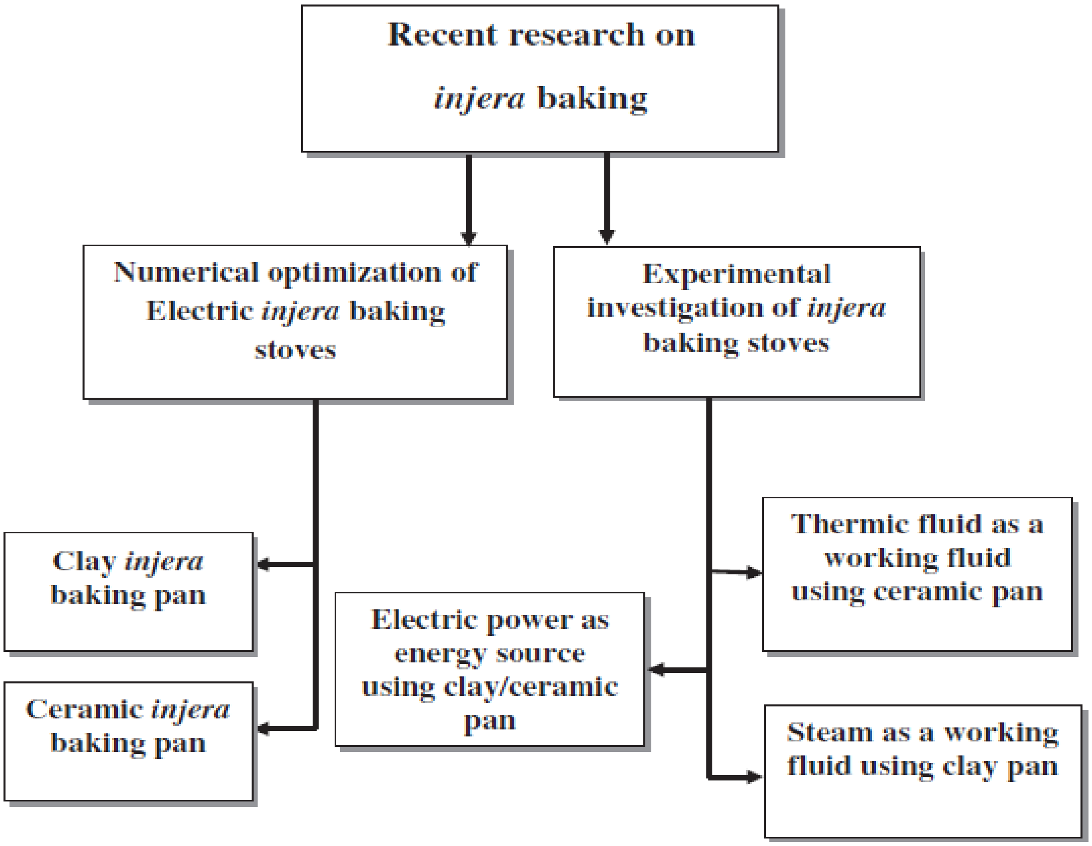


Figure 2.3 Recent research efforts(Mohammed et al., 2023)

Figure 2.2 displays current research endeavors aimed at enhancing the injera baking stove. Recent research efforts could be put to use in two ways, as the following figure illustrates: first, through numerical optimization of an injera baking stove, and second, through experimental evaluation of an injera bake stove. Numerous scholars looked at the solar and electric injera bake stoves through experimentation and numerical optimization. Conversely, a few researchers looked into the biogas injera baking stove and shared their findings using CFD software and the numerical optimization method, or FEM. Researchers have also looked into the use of clay or ceramic pans for injera baking stoves that run on electricity. Based on working fluids, such as steam using a clay pan and thermic fluid using a ceramic pan, solar power injera baking stoves were discussed (Adem & Ambie, 2017).

2.3. Combined Research Efforts

Early and recent research efforts made by different scholars towards to injera baking stoves were presented below according to their contribution.

Bicks, 2020 examined energy yield from food waste by assessing the daily waste generation rate from the university student cafeteria and configuring the baking stove (mitad) that utilizes biogas energy. The result reveals that the measured average daily biodegradable food waste is around 863 kg/day, which yields 43.2 m3 of biogas per day, reducing firewood consumption by 5.4%. Does not generate smoke and conserve heat loss to the surrounding area due to the type of fuel used and the insulation mechanism.

Salunkhe et al., 2012 investigated on biogas technology, which allows efficient capture and utilization of biogas (approximately 60% methane and 40% carbon dioxide) for energy generation. The results indicated that the composition of food waste results in varying degrees of methane yields, and thus the effects of mixing various types of food waste and their proportions should be determined on a case-by-case basis.

Chandra et al., 1990 conducted on the performance evaluation of biogas burners with various brands, the results of the tests reveal that the burner efficiency is a strong function of biogas flow pressure, pan size, and its position over the burner head.

Chandra et al., 1991 studied on hydro dynamical modelling of a biogas burner, the results showed that this modeling's u useful for optimization of the design parameters of a biogas burner

Kebede & Kiflu, 2014 conducted on the design of a biogas stove by covering the flame with an insulated material for Injera baking applications. The result showed that the newly designed gas burner was used to supply pressure equally to the holes of the burner port and to analyze heat transfer between the burner and the wall by radiation, convection, and heat transfer between the flame and the wall

Yirgu et al., 2017 focused on the design and optimization of an improved biogas Injera baking burner for uniform heat distribution of the burner throughout the baking pan. To get the optimum cooking heat distribution of an Injera baking burner, the optimum design size, number of holes on the burner, proper mixing of air and fuel flow rate were analyzed. The result obtained showed that the optimum burner manifold diameter is 26cm for better efficiency.

Petro et al., 2020 conducted on designing and improving the efficiency of the locally manufactured burners to achieve a uniform flow of fuel in the mixing chamber, which will result in consistent heat distribution around the cooking pot. The results showed that the optimum hole diameter of the jet was

2.5 mm and that of the manifold was 100 mm. The currently developed biogas burner has a thermal efficiency and fuel consumption of 67.01%, 736 g/L, compared with two locally made burners (54.61%, 58.82%, 920 g/L, and 833 g/L, respectively).

Ferrer et al., 2011 characterized biogas production in household digesters located at high altitude, operating with digester sizes of 2.4 and 7.5 m^3 at residence time (HRT) between 60 and 90 days. The study indicated that specific biogas production, methane content and inside temperature of 0.35 m3 /kg, 65% and 20 and 25 °C, respectively.

Hosseini & Wahid, 2015 investigated on biogas feedstock and its generation cycle with characteristics of biogas are investigated under various combustion regimes.

Keramiotis & Founti, 2013 carried out a comprehensive experimental characterization of a state-of-the-art porous burner fueled with a simulated biogas mixture in terms of thermal efficiency and pollutant emissions. The results revealed that stability with respect to thermal loads, low NOx and CO levels, CO2 addition on burner operation and efficiency, and the relative impact of thermal load on temperature and emission values with respect to equivalence ratio were investigated.

Nega et al., 2021 studied the design, assembly, and heat distribution tests of the Injera bakery in Ethiopia. Additionally, the thermal distribution throughout the baking pan is tested by utilizing an 8.5-m^3 biogas digester. The test results obtained showed a better temperature distribution of the improved Injera baking stove in terms of cooking duration, specific fuel consumption, and a cooking capacity of 57 %. It can bake on average $20 - 25$ pieces of Injera per day.

Jadhav et al., 2015 conducted on a burner suitable for domestic cooking that will use biogas as a fuel. For that matter, computational fluid dynamics is used to simulate the combustion of biogas on burners, and genetic algorithms are used to optimize the design of burners. The results verified that the development of such burners leads to more efficient use of biogas without its waste.

Zigale, 2020 investigated the comparative analysis and performance evaluation of three biogas-cooking stoves for Injera baking. The result showed that the copper burner stove with composite mitad consumed up to 6.9 L of biogas fuel, 75 minutes of cooking time, and 77.2% of efficiency. While a copper, burner stove with traditional mitad saved up 8.6L of biogas fuel, 78 cooking times, and an efficiency of 62%. A copper burner stove with a temper glass mitad saved up to 3 L of biogas fuel, a cooking time of 30 minutes, and an efficiency of 85%.

Keresemua, 2023 studied on design, development and experimental investigation of multi-purpose biogas stoves. The experimental test has shown that the thermal efficiency for the Injera baking part of the stove is 87.8% and for the cooking part of the stove is 65.2% respectively. Due to the equal distribution of gas discharge holes in radial and transversal directions, and the gas distributor which has been installed inside the burner, the baking surface temperature distribution is uniform and a good quality of Injera (spongy eye on the top and smooth surface on the bottom) has been baked.

Devi et al., 2019 investigated the combustion behavior of the n-house-developed porous radiant burner (PRB) applicable in industrial incinerators or bio-medical solid waste disposal systems. The layers are composed of silicon carbide (Si C) and aluminum (Al_2O_3) porous matrices, which act as the combustion and preheat zones, respectively. Results showed improved combustion efficiency and a decrease of 95% and 85% CO and NOx values, respectively, from biogas combustion in the newly developed PRB.

Syamsuri et al.,2003 investigated to identify and analyze the performance of the biogas stove. Various types of burners, including regular shaped burners, Cyclone 1, and Cyclone 2 were tested in this study. The results showed that the power of a cyclone burner biogas stove is higher than that using a biogas stove burner in its usual form. As for the efficiency of biogas stoves, the shape of the cyclone burner 2 is higher than the efficiency of biogas stoves that use an ordinary burner. Another aspect, namely the mass of the steam generated by the cyclone burner type 2, is greater than that of the other burner.

Hiben et al., 2020 studied the development of a briquette-based Injera baking stove. In this study, the development of a briquette-based Injera baking system that is non-existent in the market was considered a breakthrough for the expected fuel shift. The results revealed that the newly developed stove proved comparable results in terms of quality and increased efficiency by 28% compared to baking this food item in the traditional three-stone stoves with an efficiency of 5–15%. The main limitation was maintaining the combustion flame throughout the baking process.

Alemayehu, 2015 investigated the status and benefits of renewable energy technologies in the rural areas of Ethiopia: A case study on improved cooking stoves and biogas technologies. The results revealed that the amount of firewood saved due to the introduction of biogas was equivalent to the number of trees calculated using the literature value, i.e., 712kg of dry wood is equivalent to 6 large trees, and to produce 1kg of charcoal, 5.45kg of wood are required. Thus, using 6 trees (712 kg of wood) and 1 kg of charcoal (5.45 kg of wood) as conversion factors.

Tucho & Nonhebel, 2015 carried out on bio-waste as an alternative household cooking energy source in Ethiopia. The results showed that due to the large variation in resource availability between households, about 80% of the households own less than 2 ha and 70% hold less than 4 cows.

Abdella et al., 2023 performed an experimental investigation of a biogas Injera baking stove using a circular ring pipe burner. The purpose of this study is to solve the problem associated with burners. The results of this study reveal that the baking, idle time, and thermal efficiency of the newly developed burners are 3 minutes, 2 minutes, and 68%, respectively.

Tariku, 2020 conducted on the design, development, and performance evaluation of an improved biogas Injera baking stove. The experimental test result showed that in the first round of the baking process, the amount of biogas consumption and cooking time for baking a single Injera on an existing and newly developed biogas Injera baking stove were 9.26 litters, 1.45 litters, and 19.033 minutes, respectively.

Decker et al., 2018studied on development and test of a design approach for optimizing flame port geometry for household biogas fired burner. The result indicated that hydraulic diameter, velocity and mixture density are relevant factors in port geometry design to improve thermal efficiency of burner. Conversely, the emission predictions made by the model were found to be unreliable and incongruent with laboratory experiment.

Olubiyi Obada et al., 2014performed on the design and fabrication of burner system operating on biogas, for uses remote in region of developing country such as Nigeria and focused on characteristics such as simplicity, cost effectiveness, efficiency and safety. Mild steel, brass, galvanized pipe locally selected for the construction the results revealed that the unstable flame observed could be the results of plentiful burner ports at the top of burner system.

Gao et al., 2011carried out on biogas combustion in two-layer porous burner packed with spherical alumina beads was experimentally investigated to provide guideline for biogas burner design. The present study results showed that the stable operating ranges extends and shifted to larger value when the equivalence ratio increased.

Hosseini & Wahid, 2015conducted on experimental and numerical investigation to analyze the effect of burner configuration on the characteristics of biogas flameless combustion the results illustrate that the volume of the flame is wider in tangential burner and, hence, the temperature uniformity in the tangential flameless burner is more than coaxial configuration.

Devi et al., 2020conducted on a comparative performance analysis newly developed side way faced porous radiant burner with a commercially available conventional burner. comparative study of both burners have been in terms of thermal, combustion efficiency and pollutant emission the present experimental investigation confirmed that sideway faced porous radiant burner deliver a superior performance at all test cases the finding from the present research work provide an insight into the development of energy efficient and clean burner for crude biogas application.

Kurchania et al., 2010 performed on design and performance evaluation of biogas stove for community cooking application the results obtained showed that the gas consumption rating of the developed stove was $1m^3$(19MJ/h) and the cooking efficiency of the stove was recorded to be about 43.96%.

Sun et al., 2021 conducted on design of partially premixed burner for biogas fired wall mounted boiler which has the heat input of 25KW and can be used for space heating water heater tank heating the results indicated that the burner shows a superior performance when a jet diameter is 2 mm. meanwhile, the primary air ratio satisfies the design requirement.

investigated on flame stability limit of low swirl burner - effect of fuel composition and burner geometry the results revealed that the biogas flame stability limit is highly sensitive to fuel composition and fuel jet geometry plays a key role in reducing the dependency of the stability of swirling non premixed on flame composition.

J.O et al., 2020 studied on the cooking performance of developed biogas burner: the results obtained sowed that the gas consumption rate for the developed stove was 5.687 m^3/h. mean time measurements obtained were 5min,34.33min,34.66min and 49.33min, and biogas consumption rate $0.474m^3$,$3.254m^{3,}$3.285m3 and $4.778m^3$ for, boiling water, cooking rice, yam and beans respectively.

The efficiency value obtained are 42% for boiling water,63% cooking rice,61% for cooking yam and 30% for cooking beans

Bajet, Jr. et al., 2012 focused on modifying liquefied petroleum gas stove burner to suit for biogas fuel the results revealed that the modified LPG stove burner produced blue flame in three layer, no flue gas coming out from the burner thus fire health and environmental hazards minimize.

Decker et al., 2017 investigated on modeling tool for household biogas flame port design. The results of the study indicated that designing targeted range of port hydraulic diameter, velocity and mixture density in the tool is relevant way to improve the thermal efficiency of biogas burner.

studied on the combustion characteristics of biogas in porous radiant burner designed for domestic cooking appliance. developed porous biogas burner consist of two layer of porous matrices silicon carbide (sic) and alumina Al_2O_3 and operated in the biogas flow rang of 177 to 530 l/h with stable equivalence ratio range of 0.75 to 0.95. the results confirmed that the temperature difference between the center and periphery of the burner surface found is found to be 83^0C at an equivalence ratio of 0.95.the thermal efficiency varies in the range of 51-62% and its maximum is at 0.75 equivalence ratio and 177l/h flow rate of biogas CO emission is in the range of 29-80ppm and NOx was lower than 4ppm.

Singh et al., 2019reviewed on the performance of biogas stove from different design of burner.in this study designed three types of burner namely burner A with 115 holes of 1.5 mm size, burner B 41 hole with 3mm size and burner C 44 holes of 2mm size by placing this burner in place of regular burner for boiling water reach maximum flame temperature 1261.023^0 C for A,1226.01^0C for B and 1317.929^0 C for C and the temperature rise in the burner A, B and C are 0.31^0C,0.403^0C and 0.273^0C respectively.

Suslov et al., 2019performed on development and research of lower pressure injection burner for biogas combustion. a low pressure injection burner with conical section heat diffuser has been designed. A diffuser placed in the burner body provides pre heating of gas air mixture and allow to increase the flame propagation velocity. a computer simulation of the gas air mixing process made of three types of burner. without a diffuser, with a diffuser 11 mm and 25.5 mm long. Experimental results provided that placement of 11mm diffuser in a burner body reduce the time for heating water in the tanks up to 100^{0}C by 6%(45.41s) 25.5 mm diffuser reduces the heating time 1.5% more (11.37 s) the presence of burner in the burner increase flame propagation velocity and heat rate of the burner.

Yatim et al., 2018carried out on burner design for biogas fueled stirling engine for electric power generation the results indicated that the burner is made of stainless of steel to allow operating temperature up to 1000^{o}C and corrosion resistance.

Godoy et al., 2012 performed on the development of burner for biogas generation and describe the development of a system of automated biogas burner which record the amount of biogas burnt by a biogas low flow system the system developed showed that the effect of disposed gas produced by burner and converting it in to CO_2 proved to show less environmental impact.

Date & Search, 2019 experimentally investigated on the effect of burner exit geometry on the stability of a premixed biogas flame. Two different burner geometries were tested; a 43.5 mm long cylindrical or conical with an angle of 15 degrees, with the bluff-body was either flushed with the exit of the burner or recessed. The results showed that attached biogas flames were observed at all test conditions explored in this thesis. The results revealed that the conical burner promotes higher flame divergence than the cylindrical one, and hence becomes in direct contact with the burner inner wall. The experimental results also showed that recessing the center body, when using a cylindrical burner geometry, enhances flame stability.

Colorado & McDonell, 2018performed on the experimental study of the stability limit and emission of surface stabilized combustion burner using biogas and natural gas Surface stabilized combustion is fuel flexible technology that extends lean stability limits, widens the operation range of lean premixed systems, and is able to achieve ultra-low NOx emissions <10ppmdv. The technology has been widely used for natural gas fired devices including domestic boilers, radiating heaters, dryers, etc. The experimental results indicate that the radiant mode is established at a velocity ratio higher than 1.4. Since for the most diluted biogas by volume (65% CO2/35%CH4) this ratio is always higher than 2, the burner does not attain the radiant mode operation for this fuel type. The burner is able to burn this wide array of fuel compositions without any modifications.

Orhorhoro et al., 2018carried out design and construction of improved an improved biogas stove The results obtained show that an average efficiency, minimal efficiency, optimal efficiency of 56.894 %, 46.02 %, and 63.87 % respectively were obtained. Also, an average mass of water of 3.5 kg, an average evaporated mass of water of 0.0208 kg, and an average mass of fuel of 0.0551 kg were obtained. With this designed and adoption of biogas fuel stove as means of cooking, the usage of wood and fossil fuel will be reducing, thus preventing the liberation of hazardous gases to our eco-system.

Noor et al. 2013 discussed on the design and development of the Moderate and Intense Low Oxygen Dilution (MILD) combustion burner using Computational Fluid Dynamics (CFD) simulations. The burner simulation results showed that MILD combustion was achieved for the oxygen mole fraction of 3-13%. The final design of the burner was fabricated and ready for the experimental validation.

Santos et al., 2014investigated on lighting by biogas burner The development of efficient components to save energy plays an important role in designing of sustainable solutions. Based on the concept of green energy, gas burners based on porous ceramic structures are interesting technologies to supply heat and lighting by burning even low calorific fuels as biogas. For this study a mixture of rare earth oxides—yttria (YTR) was selected as raw material, considering the unique luminescence proprieties of rare earth elements. The results produced showed that colloidal processing of rare earth powders. The results highlighted the potentiality of these components to be applied as biogas burners.

Sokolov et al., 2017studied on use ceramic injection molding technology to increase biogas burner efficiency the results obtained confirmed that Ceramic injection molding technology improves uniform distribution of the materials. A better movement over the body the mold enables to avoid places of stress concentration such as pits and pores in a produced element. This also considerably improves physical and mechanical properties of a baked item. CIM process actually removes all limitation on complex forms of produced part and enables to obtain any surfaces.

Suslov et al., 2018investigated on to the question of biogas combustion in vortex burners The possibility of using the GGV-100 vortex gas burner for burning bio gas with a reduced methane content is considered. a computer model of the GVV-100 vortex gas burner was developed, as a result of the calculation, patterns were constructed of the change in the speed of the gas-air mixture in the longitudinally vertical plane of the section of the gas burner-furnace.

Kaewpradap et al., 2017experimented on cellular premixed flames of synthetic biogas composition effect on flat burner. The results showed the variation of biogas compositions, equivalence ratio and firing rate affected to cellular flames owing to the intrinsic instability. Moreover, it was concluded that small cell size, higher light emission and narrower unstable range and wider flame range obtained in the combustion of biogas produced from cow dung composition, was more stable compared to biogas from agricultural waste and food waste compositions.

Ufuoma and Omonigho. 2022 conducted on the development of biogas burner stove from aluminum alloy scrap. The performance of the burner was analyzed and evaluated. An average of 3.10 seconds flame transmission time for the burner port-holes with burner stove efficiency of 50%, were recorded. Also, an average of 0.24 m3 /min methane from biogas boiled about 1 liters of H_2O in approximately 8.5 minutes.

Schiro et al., 2017investigated on Gas fired boiler perspective for near future fuel composition and impacts on burner design process. A test protocol highlighting the burners' flexibility in terms of mixture composition is adopted and the system fuel flexibility is characterized around multiple reference conditions.

Godoy et al., 2012investigated on to develop a system of an automated biogas burner which records the amount of biogas burnt by a biogas low flow system. the results showed that The automated system used in the small sewage treatment plants was almost insignificant when analyzed separately but when taken into consideration several systems working together there was a considerable positive environmental impact.

Mahmoudi et al., 2013performed on the stabilization mechanism and structure of a turbulent non-premixed flame in a biogas mixture in a hot and diluted Coflow mimicking the MILD combustion are studied experimentally and numerically. The results revealed that Analysis of the luminescence images shows that the mechanism governing the lift-off process of biogas flame is similar to that of natural gas flame in which ignition kernel generation by auto ignition is responsible for flame stabilization. Compared to the liftoff height of the DNG flame, addition of 30% carbon dioxide to the fuel found to increase the lift-off height by less than 20%. In summary, in hot Coflow burner mimicking the MILD regime, the stabilization mechanism and the flame lift-off height for biogas are very similar to those of natural gas.

Devi et al., 2020studied on impact of preheat zone properties on the flammability limit of crude biogas combustion in two-layer porous radiant burner. Results indicate that PZ porosity and thickness has a significant influence on flame stability. One particular case, where the PZ porosity was 7% and thickness of 15 mm offered the best lean stable combustion, within the equivalence ration of 0.75-0.97.

Milivojević et al., 2021 carried out analysis of the performance low power atmospheric burner for gas appliance for households and their impacts on the emission and stability of the burner. The findings of theoretically obtained performance prediction and optimization of atmospheric burners were experimentally investigated in purpose built test rigs for a number of variable parameters. The obtained results fully justified the proposed models of performance prediction and burner optimization.

Elkelawy et al., 2022 performed on Experimental investigation on emission and combustion characteristics of an industrial burner using biogas co-fired with diesel and biodiesel. All the fuel test results demonstrate that inert CO2 in biogas composition has a substantial influence on the chemical reactions occurring in the flame and pollutant emissions due to its dilution effect and slowing oxidation reaction. The higher inert CO2 gas ratio in biogas caused a reduction in reaction intensity, which resulted in a weaker, unstable flame and also decreased flame temperature and NOx emissions. yield as well as high fermentation efficiency.

Özdemir et al., 2021 researched on exergy (second law) analysis of hydrogen-enriched methane, natural gas, propane, LPG, and biogas were analyzed using the numerical model in a premixed burner due to their wide usage in the industry as well as in the household appliances. The results showed that the chemical composition of the base fuel is a significant parameter that affects the exergy and energy capability of the burner due to chain reactions of radicals in the base fuel with hydrogen. It can be concluded that the hydrogen enrichment of biogas in premixed burners is promising in comparison with other tested fuels from both energy and exergy perspective.

Bhandari et al., 2014 studied on numerical study and optimization of porous burner with annular heat recirculation The results showed that flame-stability limits are lower for arrangement structure C in the combustion chamber, which is effective for heat recirculation from the flame to the pre heating zone. The burner with radially increasing and gradually varying porous media has lower flame stability limits than those with radially decreasing and gradually varying porous media.

2.4. Literature Summary

A brief examination of injera baking stove technology from ancient to modern times was included in the literature review part, as can be seen from the discussion above. It was the intention of several researchers to design and develop several kinds of injera baking stoves. People still cook their daily meals using biomass fuel in rural areas of developing nations due to a lack of grid energy. This is especially true for youngsters. People that utilize this fuel face a number of issues, including environmental degradation, health issues, deforestation, greenhouse gas emissions, and more. Several researchers designed injera baking burners based on biogas to prevent and minimize these issues. However, the main issues with previously used biogas injera baking stoves were heat loss, excessive biogas consumption, and inadequate heat distribution across the baking pan. Thus, the purpose of this study was to minimize or prevent the problems associated with biomass fuel by designing and creating circular aluminum type burner and taking into account various improvement strategies.

2.5. Literature Gap

The summary of most related literature

Author	Title	Key Findings	Method Employed	Research Gap
Mulugeta et al., 2017	Design ,Optimization and CFD simulation of improved biogas burner for injera baking in Ethiopia	The burner is too small and insufficient to bake injera	The computational fluid dynamic model employed to see the effect of heat transfer	The external manifold size is too small which is 170 mm
Decker et al., 2018	A mixed computational and experimental approach to improve biogas burner flame port design	Friction during air fuel mixture flow this reduce the flame stability	The method employed in this research work is Ansyis and solid work	Rectangular flame port are means for friction during air fuel flow
Orhorhoro et al., 2018	Design and construction of an improved biogas stoves	The maximum thermal efficiency obtained 63.87 %	The methods employed in this research work is Katia and solid work	It is only focus on the gaps between flame ports and length of mixing tube
Sukhwani et al., 2012	Theoretical and experimental performance analysis of novel domestic biogas burner	The maximum thermal efficiency obtained 42.99	The methods employed in this research work is analytical design	It is only considered variation of flame port diameter and

			procedure and Solid works	pre heating of biogas
Tariku, 2020	Design, development, and performance evaluation of an improved biogas injera baking stove	The amount of biogas consumption and cooking time is 1.45 litters and 1.6 minute respectively	The method employed in this research work is Analytical design procedures and solid works	It is very difficult for a gas to flow through a bar types of burner
Keresemua, 2023	Design, development and experimental investigation of multipurpose biogas stoves	The thermal efficiency of injera baking and cooking stoves are 87.8% and 65.2% respectively	The method employed in this research work is Analytical design procedure and solid works	Since the burner used in this research work is conical shaped it is very difficult to push the air fuel mixture at the tip of the burner

As shown in the above table, the majority of research on biogas burners concentrated on parametric study such as gas-to-air mixing rate, flow pressure, flame speed, and ignition temperature instead of enhancing the parameters of the current design, like the burner flame port hole diameter, inter port distance, injector orifice diameter, throat diameter, manifold diameter, and burner head height. Additionally, the performance of the burner was evaluated in the previous studies using liquefied petroleum and other types of gas; however, in this study, a difficulty pertaining to gas testing will be resolved by creating methane gas from cow dung and other types of waste. Furthermore, mild steel, brass, cast iron, and galvanized pipe are the materials that most researchers use in their burner designs. Apart from this, few of them use aluminum material for their burner design.

CHAPTER THREE

3. MATERIAL AND METHOD

This study was carried out in manufacturing technology and engineering industry research development center work shop which is located Addis Ababa. By incorporating the following design considerations, the current work aims to improve on the existing designs: enhancing the combustion process by introducing adequate air for combustion, reducing the amount of heat loss from the combustion chamber by insulating with asbestos, and increasing the heat transfer area by designing a circular aluminum burner with overlapped flame ports. Here is a brief discussion of the design process, fabrication process, and experimental test procedure for the recently created biogas-powered injera baking stove. When constructing an improved aluminum biogas burner for injera baking application, a number of parameters are taken into consideration. An improved aluminum biogas injera baking burner is then designed in accordance with the input parameters, yielding the desired output or outcomes. Based on the analytical design of an improved aluminum biogas burner, the newly created biogas injera baking burner was fabricated. A variety of materials, including sheet metal, flat iron, aluminum scrap, mild steel, galvanized sheet, asbestos, were used in the fabrication process to build the biogas burner. Furthermore, several Machin devices such as lath and universal milling were employed during the fabrication process. Various types of measuring instruments, including infrared thermo meter, K-type thermocouple, and gas flow meters, were used during the experimental test.

3.1. Work Flow Chart

This study involves several steps from initial point up to end. Among those step the one, which will play a crucial role in this study, mentioned in their sequence. Prior to all other steps identifying the problem related to biogas production and burner takes a front desk. The next steps will be reviewing different literature related to previously identified problem. Then set the objective, which will enable to solve the above stated problem. The final step will be preparing conceptual design biogas digester and burner, designing of burner by using solid work, selection of material for fabrication of burner prototype, constructing of prototype, conduct the experiment on the heat distribution of burner, results and recommendation. The methods applied in this study presented in figure 3.1;

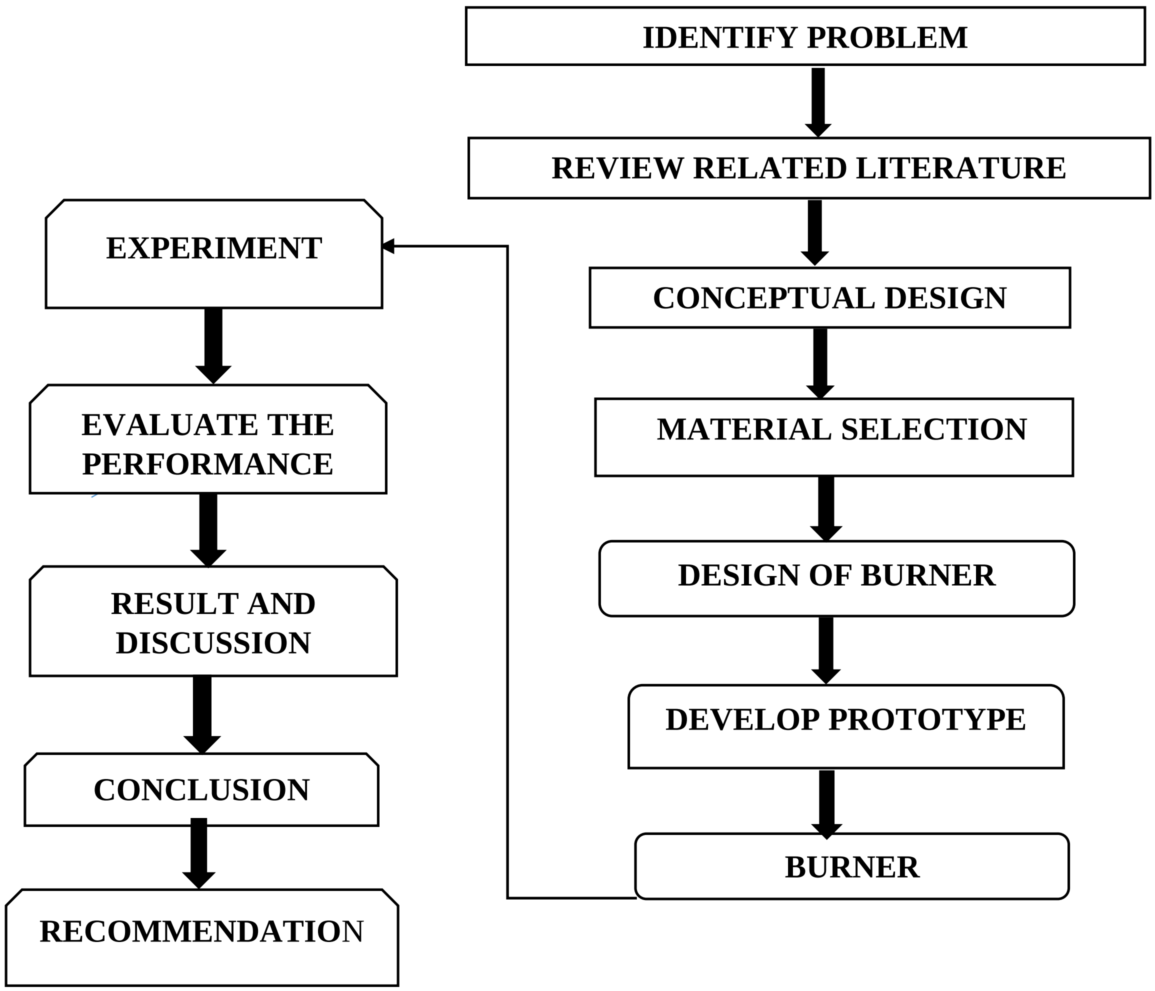


Figure 3.1 Work flow chart

3.2. Alternative Conceptual Design of Burner

Think of different geometries are crucial for choosing the best burner for injera baking applications. Early studies on biogas burners were carried out, however because of the burner's poor construction, there was an issue with the baking pan's even heat distribution. As a result, the possible geometry is mentioned and briefly explained in this section depending on various parameters. Next, decide on the best option, and design, develop, and assess the stove's performance.

The burner’s geometry selected because of the following parameters;

- flam port pattern
- pressure drop
- Temperature distribution
- Machinability

3.2.1. Circular Types of Aluminum Burner

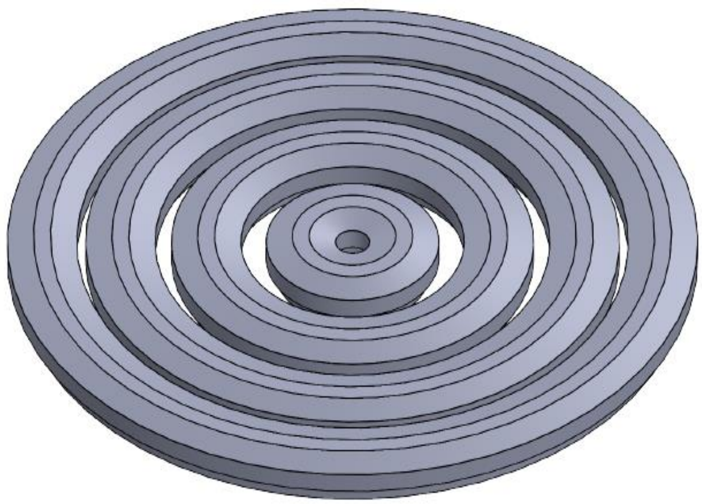


Figure 3.2 Circular types of aluminum burner

Figure 3.2 shows a circular aluminum burner with an overlapped flame port. Due to its novel geometry and overlapped flame port, the biogas distribution through this flame port is uniform due to better pressure drop, and the temperature distribution throughout the baking pan is uniform. This burner has two caps that are compatible with each other. Due to its new feature, it allows the gas to flow in both directions. The spacing between each port is kept constant at 9 mm. Each flame port has holes placed in its position; this condition can solve the problem of poor heat distribution capabilities in burners.

3.2.2. Bar Types Burner

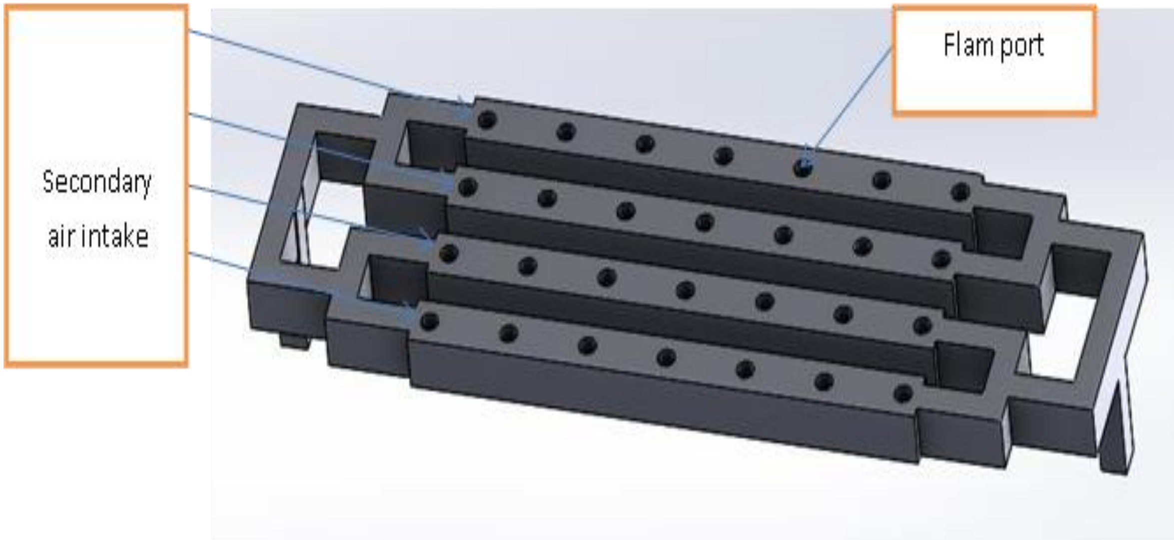


Figure 3.3 bar types of burner

A tubular burner of the bar type with several parallel flame apertures is shown in Figure 3.2. The secondary air intake, which is parallel to the flame port as depicted in the above diagram, may allow air to enter the burner's combustion chamber from both the right and left sides. The secondary air cannot pass through the center holes in this kind of flame port. Due to secondary air being unable to reach the central burner ports, this burner arrangement would result in a poor burning pattern, with the flames from those ports burning significantly higher than those at the edge [58].

3.2.3. Spiral Types of Burner

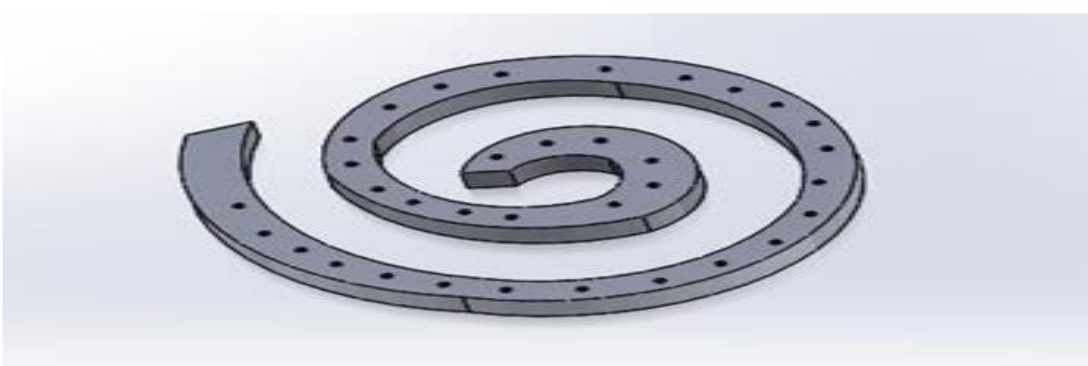


Figure 3.4 spiral types of burner

Figure 3.4. shows spherical burner. As shown in the figure above the biogas could be entering in to the burner at one side and if the distance that the gas entering in to the burner increases the pressure of the gas also decreases. For this reason, the pressure of the gas must be decreases around the central part of the burner [58]. And also the heat distribution through the baking pan could be not uniform. For this reason, because of poor construction of biogas burner the quality of injera must be decrease. In addition, the structure of this burner is complex for machining.

3.3. Material Selection

Biogas burner parts are made up of different material such as mild steels, cast irons, copper and Aluminum. among those material aluminums were selected for this work because of its good thermal conductivity properties. The selection of the material is influenced by several factors, including price, accessibility, heat treatment, and diverse engineering applications. Furthermore, the materials utilized to build the biogas stove or any of its components are robust and durable. Additionally, when the biogas stove burner is run with flames flashing back for an extended period of time in the mixing tube, the design will stop the burner parts from melting or distorting. Round mild steel is used to make pot stands, nozzles, nozzle holders, etc. because pure aluminum rode melts at a temperature of about 660°C (Rajput, 2004).

Table 3.1 Material used for injera baking stove (Keresemua, 2023)

S.N	Parts of stoves	Materials
1	Circular burner	Pure aluminum
2	Orifice	Copper
3	Support (for entire stove)	Sheet metals
4	Support (for baking pan)	Mild steel
5	Control Valve	Galvanized pipe
6	Combustion chamber	Ash with gypsum
9	Primary aeration port control mechanism	Plastic
10	Injera baking pan	Clay soil baking pan
11	Mixing Chamber	Iron Pipe

3.4. Methodology

Method of fabrication, experimental testing, prototype development, and analytical design procedures will be thoroughly discussed. This section discusses the procedure and tests, as well as the equipment employed.

3.4.1. Method of Fabrication

During fabrication, the following instruction were selected and performed

- According to their requirement different injera baking stove materials were collected
- The circular aluminum burner head manufactured by using sand casting method
- Manufacture different parts of injera baking stove according to their analytical and geometrical analysis
- assembling different parts of injera baking stove to form one stove
- the works were done

3.4.2. Method of Experiment

The Manufacturing Technology and Engineering Industry Research Development Center's work shop produced these injera baking biogas stoves. The performance of biogas fuled injera baking stoves was assessed using controlled cooking test method. The primary goal is to assess temperature distribution, thermal efficiency, baking time, injera quality, and fuel consumption.

3.4.3. Insulation

The wall of the combustion chamber used to bake Injera is insulated with asbestos. To find out if insulation is required to stop heat transmission, the thermal conductivity of asbestos is obtained from standard table 0.01W/M^{2}K which is relatively better than the previously used ash with gypsum and ash with bricks has a thermal conductivity 0.15 W/M^{2}K

Early Insulation Techniques

Current Insulation Technique

Figure 3.3 Asbestos for thermal insulation

3.4.4. Test Procedures

During experimental test of biogas injera baking stove the initial weighed and appropriate preparation was done for baking.

- The overall size and dimension of the existing biogas injera baking stove was recorded.
- By using an infrared thermo meter the temperature distribution through the baking pan of the newly developed biogas injera baking stove were measured and recorded at five points such as south, north, middle, east and west direction of the baking pan. Initial temperature of baking pan before ignitedthe fire, baking (heating) temperature of pan before baking injera on the Mitad, temperature of injera during baking, temperature of injera after baking are measured at five direction of the baking pan. The combustion temperature during baking process was measured three different measuring instruments such as infrared thermo meter, gas flow meter, K-Typethermocouple connected with digital multimeter.
- Cooking time such as the time that the stove was lit (when the fire catches), the time when the first pouring of dough took place, the time that the test ends that

3.4.5. Performance Evaluation Techniques

The biogas burner prototype will be tested using burner testing methods. Major burner testing methods are categorized as follows:

- Controlled cooking test

3.4.5.1. Controlled Cooking Test

The performance of the Injera baking stove is assessed using the controlled cooking test (CCT) method. It was selected because it works well for baking injera. The CCT is a typical cooking test that is intended to be used in the field to evaluate how well an upgraded cooker performs when a chef makes a meal for the community. It evaluates the enhanced stove's efficiency in terms of fuel and time savings in comparison to standard or conventional cooking techniques. Similar to that, the biogas Injera baking stove's performance was intended to be tested using CCT in this experiment. Next, a basic baking assignment that is comparable to the actual baking that locals undertake on a daily basis will be performed on each biogas stove to compare them all.

This method is employed to evaluate the performance in a controlled environment utilising indigenous fuels and customs for Injera baking. A minimum amount of other factors' influence is incorporated into the design of the tests. The same Injera baking Mitad, a regional product made of clay, was used for all of the testing.

3.4.5.2. Test Standards of Biogas

The thermal efficiency, emission, safety and durability of biogas in accordance with Ethiopia standard agency (ESA) 19867-1 are > 40 %, <4.4 g/MJ d, 86 and 15 respectively (www.ESA).The maximum biogas efficiency with 8mbar operating pressure obtained earlier was 51% so as to bring value which is close to this value it is necessary to perform such test.

3.4.5.3. Test Instruments

Figure 1.4 Testing Instruments

CHAPTER FOUR

4. DESIGN OF ALUMINUM BIOGAS BURNER

4.1. Design Parameter

The amount of energy needed to bake injera, biogas flow rate, the amount of air needed for complete combustion, the design of digester for biogas production, the amount of waste fed in, feed rate, injector orifice, primary aeration, flame port, mixing tube, and throat are just a few of the design parameters that were taken into consideration to ensure an efficient and optimal design.

4.1.1. Energy Required to Bake Injera

Different numerical values were taken to calculate the energy needed to bake injera below.

- The mass of the dough with in a single Injera= 581gm = 0.581 kg and 40 percent Teff flour and 60percent water make up the dough (Kebede & Kiflu, 2014.) then;
  - Water mass = 0.6 × dough mass
    = 0.6 × 0.581kg
    = 0.3486 kg of Water
  - Teff mass = 0.4 × dough mass
    = 0.4 × 0.581
    = 0.2324 kg of Teff

Baking Injera requires a temperature range of 180°C to 220°C. 200°C is the average temperature.

- Ambient temperature 21℃
- Cp of water at 21℃ is 4.174 KJ/kg ℃
- Cp of teff at 21℃ is 1.046kJ/kg℃
- Cp of dough at 21℃ is 5.22kJ/kg ℃ (Tariku, 2020)

The quantity of energy required to turn 0.581 kg of teff dough at 21 °C into steam at 100 °C is determined by:

$$p_{out} = m_{dough} \times C_{pdough}\ (T2 - T1) + m_W c_w \Delta T \tag{4.1}$$

Where: p_{out}: the quantity of power required to turn a specific mass of dough into steam at room temperature,

Where;

mw: mass of water

cw: specific heat of water

Lw: latent heat of 0.486 kg of water is 35.6K Calories which is equal to 149KJ

mdough: mass of dough,

Cp dough: specific heat capacity of the dough

$p_{out} = 0.581\text{kg} \times 5.22\text{kJ/kg°C}\ (100-21) + 0.3486\ \text{kg} \times 4.174\ \text{KJ/kg ℃}\ (100\text{-}21) = 355\text{KJ}$

Now figure out how much energy one Injera will require to bake in 2.5 minutes, or an expected time (t) will be:

$$E = \frac{\text{Pout}}{\text{t}} \tag{4.2}$$

$$E = \frac{355KJ}{150Sec} = 2.37KW\ =\ 8532\text{KJ/hr} = 8.532\text{MJ/hr}$$

The following formula determines the amount of flame combustion power needed to bake an injera:

$$\eta\ = \frac{E}{\text{Prequired}} \tag{4.3}$$

When designing the injera baking biogas burner, (Nega et al., 2021) analytical design process was used as a model. Consequently, approximately 1.5 kw of total output power is needed for baking injera. With a biogas pressure of 8 mbar, Ethiopia's average big-scale biogas burner efficiency (RH) is currently 51%. From output power and average stove efficiency (ηav), one can therefore compute the power needed and the volumetric flow rate of biogas for injera baking(Yirgu et al., 2017).

$$\text{Prequired} = \frac{\text{E}}{\eta\text{av}} \tag{4.4}$$

$$\text{Prequired} = \frac{2.37\text{KJ}}{0.51}\ = 4.64\text{KW}$$

4.1.2. Biogas Flow Rate Calculation

Calculating the power necessary for the process to meet the required power input Cv= 22 MJ/m3 required knowledge about the biogas flow rate. the gas through the stove (Q, m3⁄h) can be determined as set in (4.5)(Frederik's, 2012).

$$\text{Qbiogas} = \frac{\text{Energy needed}}{\text{Calorfic Value}} \tag{4.5}$$

$$\mathrm{Qbiogas} = \frac{8.532\mathrm{MJ/hr}}{22\mathrm{MJ/m3}} = 0.387\mathrm{m3/hr}$$

4.1.3. Quantity of Air Required for Complete Combustion

A sufficient amount of air is needed for full combustion. Enough air will facilitate the release of the biogas fuel's potential heat. However, partial combustion due to insufficient air supply would result in the loss of potential heat. Understanding the stoichiometric air required for the biogas fuel's full combustion became essential. Since "equal volumes of gases under the same conditions of temperature and pressure contain the same number of molecules," as stated by Avogadro's equation, Equation 2 results from the combustion reaction (Kurchania et al., 2010).

$$CH4\,(g) + 2O2\,(g) \rightarrow CO2\,(g) + 2H2O\,(l) \tag{4.6}$$

Since there is 21% of oxygen in the air and 60% of methane in biogas, the volumes of the two substances are equivalent to 1.67 and 9.52, respectively. The volume of methane in biogas is one by 0.6 and the volume of oxygen in air is two by 0.21. As a result, $\frac{9.52}{1.67}$ = 5.7 volumes of air are needed for every volume of biogas. For biogas containing 60% methane and 40% carbon dioxide, the density is 1.67, or 1.2075 kg/m3(Bantelay, 2014).

Table 4.1 Properties of biogas (Bantelay, 2014)

Properties of biogas	**Values**
Methane content	60%
Carbon dioxide content	40%
Calorific value	(21-24) MJ/m3
Specific gravity	0.94
Density	1.2kg/m3
Flame speed factor	11.1
Combustion speed	40cm/sec
Inflammability in air	6-25%

4.1.4. Injector Orifice

Injectors control the amount of gas used by the burner and are also used to separate the burner from the gas supply. This condition allows the gas to easily reach the burner. With the help of an orifice mounted on the injector, it is possible to measure the flow rate of the gas (Fulford, 1996). The Bernoulli equation that governs the discharge of gas through an injector orifice was used. The injector orifice area is given by Equation 5 (Rajput, 2008).

Injectors on larger burners may have more than one hole, mainly to reduce noise.

The gas flow rate (Q) is related to the gas velocity (v) by the area (A) of the pipe through it is flowing:

$$Q = VA$$

For gas flow through an orifice, the area of the hole is not necessarily the area of the flow. A sudden change in flow area causes a “vena contracta”, a narrowing of the flow to an area smaller than that of the hole itself:

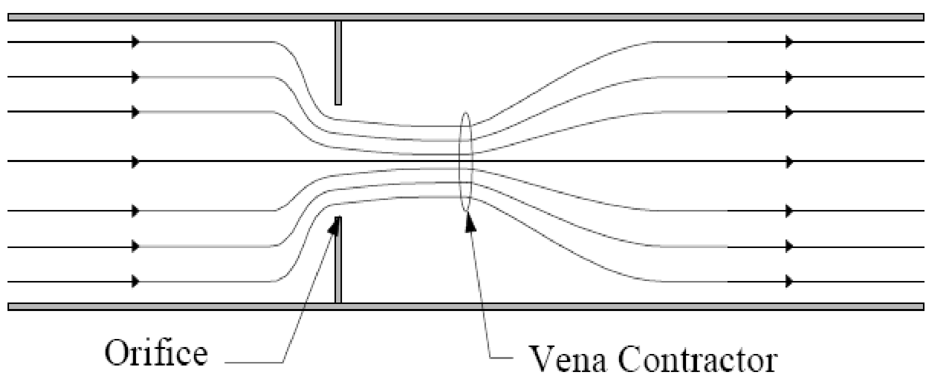


Figure 4.1 An injector orfice (Fulford, 1996)

An orifice plate can be used to measure gas flow over a very wide range of flow conditions, including very high flow rates.

Figure 4.2 Diaphragm of orfice jet with primary aeration

Gas Flow through an injector orfice (Jet)

$$Q\ gas = 0.0467C_d Adj\sqrt{Po/\rho\ substance} \tag{4.10}$$

Where;

Q= Gas flow rate (in cubic meter per hour)

Ao= Injector orifice area (mm2*)*

Cdo= Discharge coefficient (the ratio of actual to theoretical discharge rate)

P = Static gas pressure (in millibar)

ρ = density of a substance

The typical coefficient of discharge of the orifice is in the range of 0.85 to 0.95. To maximize Cd, the orifice channel length should be 1.5–2 times the orifice diameter. It is expected that there will be a gas supply pressure of 8 mbar, a suitable injector with a Cd of 0.94, a vena contractor, and friction losses through the orifice(Fulford, 1996).

Table 4.2 Density of gases (Friedlingstein et al., 2020)

Gases	Density (Kg/m^3)	Air density taken as reference density of 1kg/m^3.
Air	1.274	1
Methane	0.7057	0.554

Carbon dioxide	1.9359	1.519
Biogas	1.25	0.981

To calculate the density of biogas by summing percentage density of its content given by:

$$= \quad 0.6 \times \rho CH_4 + 0.4 \times \rho CO_2 \tag{4.11}$$

$$= 0.6 \times 0.554 \text{ kg/m3} + 0.4 \times 1.519\text{kg/m3}$$

$$= 0.94 \text{ kg/m3}$$

Then the specific gravity of biogas (*S*) can be calculated as:

$$S = \frac{\text{density ofsubstance}}{\text{density of refernce}} \tag{4.12}$$

$$S = \frac{0.94\text{kg/m3}}{1\text{kg/m3}} = 0.94\text{kg/m3}$$

$$\text{Q gas} = o.0467 \frac{\pi dj^2}{4} \text{Cd} \sqrt{\text{P}}/\rho \text{ substance} \tag{4.13}$$

Now calculate for diameter of jet (dj) is by arranging equation set in (4.5) will be

$$dj^2 = \frac{0.387\ m3/hr}{0.0366 \times 0.94\sqrt{\frac{8mbar}{0.94}}kg/m3} = 3.9mm$$

The Injera baking and cooking stoves are two examples of applications that operate in a single system. While the diameter of the jet orifice is 3.9 mm, for optimal gas flow the diameter of the orifice should be between 5 mm.

- The area of the jet will be determined as:

$$\text{Aj} = \frac{\pi dj^2}{4} = \frac{\pi(5mm)^2}{4} = 20mm \tag{4.15}$$

- The velocity of gas in the orifice (V_o) is:

$$\text{Vj} = \frac{Qbiogas}{3600Aj} = \frac{0.387}{3600\times0.00002\text{m2}} = 0.7 \text{ m/s} \tag{4.16}$$

4.1.5. Mixing Tube Diameter and Length

The minimum diameter for a cylindrical throat is required to ensure adequate gas and air mixing. The mixing tube's length should also be sufficient. The mixing tube and diffuser working together changes the amount of air entrainment throughout their length, both upstream and downstream of the throat. Ten to twelve times the neck diameter should be the length of the mixing tube, and two to three times the throat diameter should separate the injector from the throat entry (Harniet et al., 2004).

Given that the stoichiometric primary aeration needed for the entire combustion process is 5.5, the entrainment ratio (r) should be 5.5/2 = 2.75.

Methane can be converted into two volumes of steam and one volume of carbon dioxide for every two volumes of oxygen. Given that 60% of biogas contains methane and that the air contains 21% oxygen,

$\frac{1}{0.6} = 1.667$ volumes of biogas require $\frac{2}{0.21} = 9.52$ volumes of air. One volume of biogas requires $\frac{9.52}{1.667} = 5.71$ volumes of air, or $\frac{1}{5.71} \cong$ 15% biogas in air.

Stoichiometric air need is the term used for this. Biogas will only burn in a very limited range of air mixes, from 9 to 17 percent biogas. When there is too much fuel in the flame, it becomes "too rich," which causes it to burn poorly and inefficiently, producing toxic soot and carbon monoxide (Jadhav et al., 2015).

By using prigs' formula, the diameter of throat (d_t):

$$\mathrm{dt} = \left(\frac{r}{\sqrt{s}} + 1\right) dj \qquad (4.17)$$

$$\mathrm{dt} = \left(\frac{2.5mm}{\sqrt{0.94kg/m3}} + 1\right) 5mm = 16.6mm \approx \ 20\mathrm{mm}$$

The throat diameter of for Injera baking stove is 20mm (petero et al., 2004). So, the diameter of the throat is approximated to 20mm is fine. The area of air inlet ports must have the same to that of the throat (Fulford, 1996). However, it is better to increase this value to give an aeration much greater than optimum and then use air controls to adjust theair flow. And if the diameter of the throat is found the area of the throat is given by:

$$\mathrm{At} = \frac{\pi \mathrm{dt}^2}{4} \tag{4.18}$$

$$\mathrm{At} = \frac{\pi(20\mathrm{mm})^2}{4} = 314\mathrm{mm2}$$

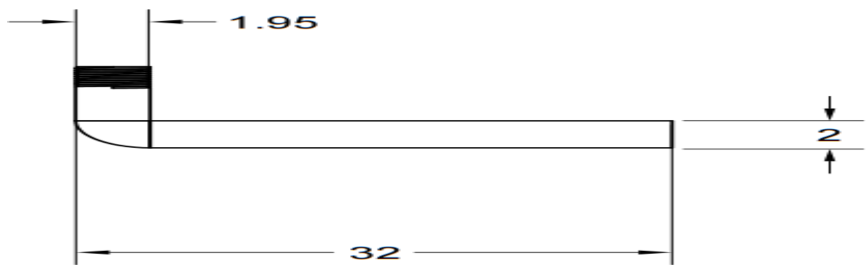


Figure 4.3 Mixing chamber (Keresemua, 2023)

The area of air inlet ports must have the same to that of the throat (Fulford, 1996).

4.1.6. Throat Gas Flow Rate

The velocity of gas in the throat calculated by using the formula:

$$\mathrm{Vt} = \mathrm{Vj}\ (\frac{\mathrm{dj}^2}{\mathrm{dt}^2}) \tag{4.19}$$

$$\mathrm{Vt} = \frac{0.7\mathrm{m}}{\mathrm{s}\left(\frac{5\mathrm{mm}^2}{20\mathrm{mm}^2}\right)} = \quad 0.04375\mathrm{m/s}$$

4.1.7. Throat Gas Pressure

The pressure of gas in the throat is given by:

$$\mathrm{Pt} = \mathrm{Po} - \rho \frac{\mathrm{Vj}^2}{2\mathrm{g}} [1 - \left(\frac{\mathrm{dj}^4}{\mathrm{dt}}\right)] \tag{4.20}$$

Where: P_o is the atmospheric pressure 100,000Pa. Methane has a density of about 0.75 kg/m³
ρ is density of gas is 1.0994 at standard pressure and temperature.

$$\mathrm{Pt} = 100{,}000Pa - 1.0994 \frac{\frac{0.7m^2}{s}}{2 \times \frac{9.81m}{s}} [1 - (\frac{5mm^4}{20mm}) = 99.999 \times 103 \text{ Pa}$$

Biogas has a denser than natural gas, with a density of 1.25 kg/m^3, due to carbon dioxide's relative weight (Teffera and Wubu, 2016). So, let take the density of biogas is 1.25 kg/m^3, g is the gravity acceleration which is 9.81 m/s^2.

4.1.8. Throat Mixture Flow Rate

The flow rate of mixture of biogas and air is given by (Kebede & Kiflu, 2014.).

$$\mathrm{Qm} = \frac{\mathrm{Qbiogas}\ (1+\mathrm{r})}{3600} \tag{4.21}$$

$$\mathrm{Qm} = \frac{0.387\ \mathrm{m3/hr}\ (1+2.25)}{3600} = 0.000349\ \mathrm{m3/s}$$

4.1.9. Throat Pressure Drop

Before go to calculating pressure drop, the Reynold number must be checked.

$$\mathrm{Re} = \frac{4\rho\mathrm{Qm}}{\pi\mu\mathrm{dt}} \tag{4.22}$$

ρ is the density of the mixture 1.15 kg/m3, and μ is the viscosity of the mixture1.17×10^{-5} pa (Kebede & Kiflu, 2014).

$$\mathrm{Re} = \frac{4\rho\mathrm{Qm}}{\pi\mu\mathrm{dt}} = \frac{4\times1.15\times\ 0.000349\mathrm{m3/s}}{\pi\ \times\ 1.17\ \times\ 10-5\times\ 0.02\mathrm{m}} = \quad 2183.8$$

If the Reynold number is greater than 2000, the formula for *f* is given as:

$$\mathrm{f} = \frac{0.316}{\mathrm{Re}^{0.25}} = 0.036 \tag{4.23}$$

L_m is the length of mixing chamber, $L_m = 15\times d_t$

$L_m = 15\times 20 =$300mm long

The pressure drop is given by:

$$\Delta\mathrm{P} = \frac{\mathrm{f}}{2}\rho\mathrm{Vt}^2\frac{\mathrm{Lm}}{\mathrm{dt}} = \frac{\mathrm{f}}{2}\rho\frac{16\mathrm{Qm}^2\mathrm{L}}{\pi^2\mathrm{di}^5} \tag{4.24}$$

The pressure drop is calculated from the equation set in (4.20) as below:

$$\Delta\mathrm{P} = \frac{\mathrm{f}}{2}\rho\frac{16\mathrm{Qm}^2}{\pi^2\mathrm{dt}^5}\ \mathrm{Lm} \tag{4.25}$$

$$\Delta P = \frac{0.036}{2} \times 1.15\frac{\text{kg}}{\text{m3}}\frac{16\ \times\ 0.000349m3/s^{\ 2}}{\pi^{2}\ \times\ 0.02^{5}} \times 0.3\ \text{m} = \ \ 0.383\text{Pa}$$

$\Delta P = 0.383$ pa, this pressure drop is much lower than the driving pressure in the throat.

4.1.10. Design of Burner Flame Port

The baking pan's bottom can be heated by the flames radiating from flame ports. The baking stove's heat efficiency is dependent on the quantity and placement of its flame apertures. The stoichiometric biogas flame is only burning at a pace of 0.25 m/s (Kebede & Kiflu, 2014).

The mixing supply velocity V_p is given by equation (4.26)

$$\text{Vp} = \frac{\text{Qm}}{\text{Ap}} < 0.25\ \text{m/s} \tag{4.26}$$

Where A_p is the total burner port area in m^2 = $\text{np} = \frac{\pi \text{dp}^2}{4}$

np-the number of ports

dm-diameter of ports in m

$$\text{Ap} > \frac{\text{Qm}}{0.25} \tag{4.27}$$

$$\text{Ap} > \frac{0.000349}{0.25} > 1.396 \times\ 10 - 3\text{m2}$$

Using 2.5 mm diameter of holes, the total number of ports required will be:

$$\text{np} = \frac{2\text{Ap}}{\pi \text{dp}^2} \tag{4.28}$$

$$np = \frac{2Ap}{\pi dp^{2}} = \frac{2\ \times 0.001396}{\pi \times 0.0025\ \text{m}^{2}} = 345.7 \approx 348$$

4.1.11. Baking Stove Burner Diameter

To enhance the distribution of heat to the pan's bottom, 348 holes should be drilled around the burner head at equal radial and transverse spacing. There are 9 mm between each adjacent port, or transversal, between them. The distance between each hole is calculated as follows to determine how many holes of a particular diameter can be drilled:

$$\text{Cb} = 2\pi \text{R} = +\text{np}\ (\text{dp} + \text{Pg}) \tag{4.29}$$

$$\text{np} = \frac{\pi D}{(dp+dg)} \qquad (4.29a)$$

Where D: the diameter of the burner

n_p: the number of ports to be installed

d_p: port diameter

p_g: gap between the port

$$\text{Cb} = 2\pi\text{R} = 348\ (0.0025 + 0.018) = 7.138$$

As a result, there are 348 holes punctured at diameter of 467mm. 43 holes at a diameter of 117 mm, 63 holes at a diameter of 245 mm, and 103 holes at a diameter of 348 mm, 139 holes at a diameter of 467.

For the Injera baking burner, there are 348 ports; however, for the cooking stove, these ports will be reduced by a certain amount in the event of flame stabilization, as will be discussed in the next section.

4.1.12. Height of Flame

Flame height determination is determined by;

$$\text{Hf} = 0.235P\text{required}^{2/5} - 1.02dp \qquad (4.30)$$

Where,

H_f is the height of the flame

d_p is the diameter of the flame port

The port is calculated as the ratio of the total energy needed to the number of flame ports. The total power required is 2.62 kw.

So, for a single hole, the power required is

$$4.64\text{kw}/348 = 0.013\text{kw}.$$

The height of the flame from equation (4.30) will be:

$$H_f = 0.235P_{\text{required}}^{2/5} - 1.02d_p$$

$$H_f = 0.235 \times 4.64^{2/5} - 1.02 \times 0.003\text{m} = 0.043094\text{m} = 43\text{mm} = 4.3\text{cm}$$

Light Back

Light back occurs when there is little heat input, when there is little aeration, or when the gas flow and burning velocities are not constant. Now, instead of going away, the light is returning. The apertures' diameter is the primary element obstructing light return. When the flame port is somewhat narrow, as opposed to wide, it is more susceptible to backlighting.

4.2. Heat Transfer Analysis

This section provides an introduction to heat transfer, including its mechanism, heat loss, and available data for analytical calculations. The heat transfer analysis of the injera baking stove is covered in the following sections.

The presence of a temperature difference is the fundamental prerequisite for heat transfer, as heat transfer is the measurement of the rate at which energy can be transferred from one form to another as a result of a temperature difference. Two media at the same temperature cannot transfer heat in any net way. In a given direction, the magnitude of the temperature gradient determines the rate of heat transfer in that direction. Higher heat transfer rates are associated with larger temperature gradients.

There are three different ways that heat can be transferred: conduction, convection, and radiation. All of these heat transfer modes involve the transmission of heat from a high-temperature medium to a lower-temperature medium, and they are all dependent on the presence of a temperature difference.

- Conduction: In Conduction heat transfer occurs between objects by direct contact.
- Convection: In convection, the heat transfer takes within the fluid.
- Radiation: In radiation, heat transfer occurs through electromagnetic waves without involving particles.

4.2.1. Heat loss and transfer characteristics of injera baking pan

The injera baking stove can lose heat in three different ways. These are top, bottom, and lateral sides. Conduction, convection, and radiation the three basic modes of heat transfer are all used by the stove. Conduction warms the injera's bottom surface, while convection and radiation help a little amount of heat move from that surface to the upper.

4.2.2. Heat transfer through the wall of insulated material

Insulation is a process of preventing the heat escaped from baking pan by using different mechanism.

Due to the existence of temperature difference between combustion chamber and environment there is always the heat loss. In order to minimize this heat loss problem, it is necessary to perform insulation.

Asbestos insulation was favored because it was strong and fireproof and relatively better than ash and gypsum mixture. The insulation was used for all types of purposes, including insulating walls, floors, pipes, ductwork, and boilers. It was also used to fireproof structural beams.

Analysis

The figure below depicts the thermal resistance network, which consists of three resistances connected in series.

The area of the surface exposed to convection is determined to be:

$$A1 = 2\pi \mathrm{r1L} \tag{4.31}$$

$$Q = UA(\mathrm{T\infty, i - T\infty, o}) \tag{4.32}$$

Q is the heat flow across the face at r equals that r+Δr and U is the overall heat transfer coefficient A is the circumferential area of the cylinder and $T\infty$ is freestream temperature inner and outer part

$$\mathrm{Q} = \frac{\mathrm{T\infty, i - T\infty, o}}{\frac{1}{UA}}$$

Where

$\frac{1}{UA}$ is equivalent or summation thermal resistance networks.

$$\frac{1}{\mathrm{UA}} = \frac{1}{2\pi \mathrm{r1Lhc,i}} + \frac{\ln(\frac{\mathrm{r2}}{\mathrm{r1}})}{2\pi \mathrm{KAL}} + \frac{1}{2\pi \mathrm{r2Lhc,o}} \tag{4.33}$$

Where

r_1 and r_2 are internal and outer radius of an insulative stove respectively $h_{c,i}$ and $h_{c,o}$ are internal and outer convectional heat transfer coefficient respectively. K_A Thermal conductivity of an insulative material.

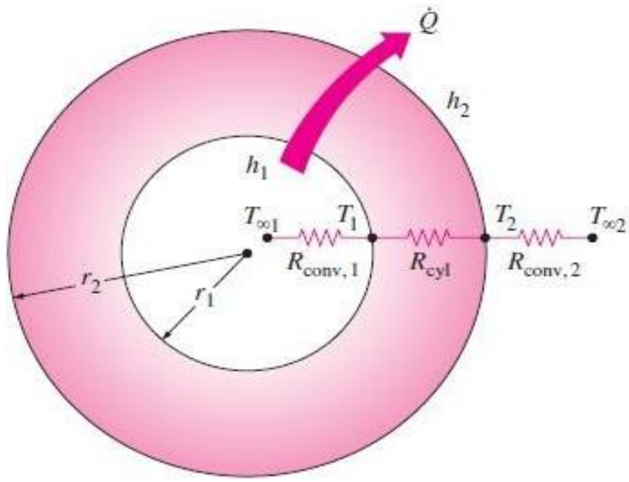


Figure 2.5 Thermal resistance network for cylindrical shell convective and radiative to the outer surface of the surrounding

However, convectional heat transfer coefficient is calculated as follow:

$$hc = \frac{Nu \times K}{Ln} \tag{4.34}$$

For vertical plate and heat flows in horizontal direction

$$Nu = 0.062(Gr)^{0.327} \tag{4.35}$$

$$Gr = \frac{g\beta\Delta TLn^3}{v^2} \tag{4.36}$$

Where,

L_n is the space between the flame and

ΔT is temperature difference between the two

β is volumetric coefficient of expansion of air

γ is kinematic viscosity

g is gravitational force

N_u is non-dimensional heat transfer coefficient

Using the convectional heat transfer coefficient hc, i = 5.674W/m2k at the stove's internal combustion temperature of 400oC and the ambient temperature of 21oC, calculate the outer convectional heat transfer coefficient hc, o =3.53W/m2k and measure the distance of 7 cm between the flame and plate.

Determine the heat flow through an insulated material by considering various alternate outer diameter dimensions and applying equations. Where the heat conductivity of an insulated wall is 0.023W/m2k and r1= 35cm = 0.35m. It is evident that when the insulating wall becomes thinner, the heat transmission coefficient increases. It is important to record the insulator's outside diameter measurement of 66 cm. The insulator's thickness is 4 cm since the outer and inner radii differ from one another. Consequently, 33 cm will be the outside radius.

4.2.3. Convectional Heat Transfer

4.2.3.1. Coefficient of convection between the pan and lid cover

Figure 4.6 displays the resistance block diagram illustrating the process of convectional heat transmission from the pan surface to the surrounding air. Heat from the pan surface is transferred to the pan lid through the injera. The temperature of the batter or injera directly relates to it. Free convection transfers heat from the surrounding air across the baking lid cover. It is possible to calculate the coefficient of heat transmission between the surface of the baking pan and the lid cover;

$$\mathrm{h1lc} = \frac{\mathrm{KNu}}{\mathrm{Lpl}} \tag{4.37}$$

where;

$h1lc$: Heat transfer coefficient b/n baking pan and lid cover

K – Thermal conductivity of evaporated water fluid

L_{pl} – Length of pan to lid covers

N_u – Nusselt number

The Nusselt number is given for a horizontal plate and a baking pan with a uniform surface temperature as follows:

$$\mathrm{Nu} = 2 + 0.6\ \mathrm{Pr}^{0.33}\mathrm{Gr}^{0.25} \tag{4.37a}$$

The recommended correlation for the heated upper surface of baking pan is given as:When,

$$\text{For, } 10^5 < \mathrm{R_a} < 2 \times 10^7 \text{ .... } \mathrm{Nu} = 0.54\mathrm{Ra}^{0.25} \tag{4.37b}$$

For, $2 \times 10^7 < R_a < 3 \times 10^{10}$............................ $Nu = 0.14Ra^{\frac{1}{3}}$ (4.37c)

$$\mathrm{Ra} = \mathrm{Gr} \times \mathrm{Pr} \quad (4.37d)$$

$$\mathrm{Ra} = \frac{\mathrm{g\beta \Delta TLpl^3}}{\gamma^2}\ \mathrm{Pr} \quad (4.37e)$$

Where, Ra-Rayleigh number,

Gr-Grashoff's number,

Pr- Prandtl number,

γ-kinematic viscosity

The air properties will be considered at mean temperature between them

$$\Delta \mathrm{T} = \frac{\mathrm{Tlc+Tp}}{2} \quad (4.38)$$

Where: ΔT: Mean temperature

T_{lc} (T_2): Temperature of lid cover (60°C)

T_p (T_1): an average temperature of baking pan (200°C)

$$\Delta \mathrm{T} = \frac{60 + 200}{2} = 130\ ℃$$

$$P_r\text{: } 1.4611,\ \gamma = 2.5\ \times 10^{-7}$$

$$\beta\frac{1}{Tk} = \quad 8.58\ \times\ 10 - 5$$

$$Ra = \frac{9.81\frac{m}{s} \times\ 0.0000858\ \ \times\ 130\ \times\ 0.1^3}{(2.5\ \times\ 10-7)\ ^2}\ \times\ 1.4611\ =\ \ 2.558\ \times\ 109'$$

$$R_a = 2.558 \times 10^{9}\ '$$

From the above result of Rayleigh number, the recommended correlation for the upper heated surface of baking pan from equation (4.37c) is given as:

$$\text{For } 2 \times 10^7 < Ra < 3 \times 10^{10} \quad (4.39)$$

$$Nu = 0.14(\mathrm{Ra})^{1/3} \quad (4.40)$$

$$Nu = 0.14(2.558 \times 10^{9})^{1/3} = 196.46$$

$$Nu = 191.46$$

There for the convectional heat transfer coefficient between baking pan and lid cover from equation (4.37) becomes:

$$\text{h1lc} = \frac{KNu}{Lpl} \tag{4.41}$$

$$\text{h1lc} = \frac{0.68 \times 191.46}{0.1} = 1302 \text{ W /m2K}$$

4.2.3.2. Coefficient of convection between lid cover and surrounding air

The determination of convective heat transfer coefficient from lid cover to ambient could be given as:

$$\text{h2lc} = \frac{\text{KNu}}{\text{Lpl}} \tag{4.42}$$

$$\text{Ra} = \text{Gr} \times \text{Pr}$$

Thermal expansion of common gases is the reciprocal of temperature. The volumetric thermal expansion coefficient of any permanent gas (at constant pressure) is given by:

$$\beta = \frac{1}{\text{Tk}} \tag{4.43}$$

Consider property of air

$$\Delta T = Tlc - Ta = 60 - 21 = 39℃ \tag{4.44}$$

$$Tk = 273 + 39 = 312 ℃$$

$$\beta = \frac{1}{312} = 0.0032$$

$$Ra = \frac{g\beta\Delta T Lpl^{3}}{\gamma^{2}} Pr \tag{4.45}$$

$$Ra = \frac{9.81 \times 0.0032 \times 39℃ \times 0.6^{3}}{(1.701 \times 10-5)^{2}} \times 0.7255 = 6.79 \times 108$$

For horizontal plate and uniform surface temperature Nusselt number, the recommended correlation for the upper heated surface of baking pan is given by:

$$N_u = 0.14(R_a)^{1/3} \qquad for\ 2 \times 10^{7} < R_a < 3 \times 10^{10} \tag{4.46}$$

$$N_u = 0.14(6.79\times108\ )^{1/3} = 123.1$$

Therefore, the convectional heat transfer coefficients from lid cover to ambient isdetermined as follow:

$$\text{h2lc} = \frac{KNu}{Lpl} \tag{4.47}$$

From the thermal conductivity of lid cover at a temperature of 60^{o}c which is 0.57

$$h_{2lc} = 32.74\ W/m^2k$$

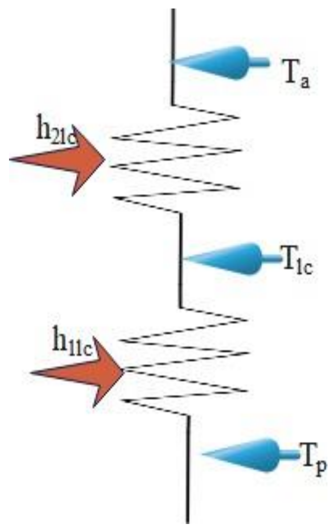


Figure 4.6 Block Diagram for convective and radiative heat transfer (Keresemua, 2023)

4.2.4. Radiation Heat Transfer

4.2.4.1. Baking pan surface to lid cover radiative heat transfer coefficient

Heat transfer from the pan surface to the lid cover and from the lid cover to the surrounding air occurs through a heat transfer method known as radiation, as shown in Figure 4.5. This results in the calculation of the radiative heat transfer coefficient. To find the radiant heat transfer coefficient between the pan's top surface and lid, the same radial shape, the same top surface, and the necessary values of the geometric components are taken into account. The total of the serial emission coefficients of the pan and the lid is the overall radiant heat transmission coefficient.

As a result, the following formula can be used to determine the radiant heat transfer coefficient from the surface of the top plate to the cover.

$$h1r = \zeta \varepsilon_{\mathrm{eff}} \left(\frac{(Tp+273)^4}{Tp-Tlc} - \frac{(Tlc+273)^4}{Tp-Tlc} \right) \quad (4.48)$$

Where;

h_{1r}- Radiative heat transfer coefficient from the baking pan to lid cover

ζ- Stefan Boltzmann constant [$5.67 \times 10^{-8}\ W/m^2k$]

ε_{eff}- Effective emissivity of the baking pan it is given by equation below

$$\varepsilon\mathrm{eff} = \left(\frac{1}{\mathrm{gp}} + \frac{1}{\mathrm{gLC}-1} \right) = 0.11 \quad (4.48a)$$

$$h1r = 5.67 \times 10-8 \times 0.11 \left(\frac{(200+273)^4}{200-60} \frac{(60+273)^4}{200-60} \right) = 1.64W/m2k$$

4.2.4.2. Radiative heat transfer coefficient from lid cover to ambient

The surrounding temperature or sky temperature is given by:

$$\mathrm{Tsky} = \mathrm{Ta} - 6 = 20 \quad (4.49)$$

The radiative heat transfer coefficient from lid cover to ambient is given as:

$$\mathrm{h2r} = \zeta \varepsilon_{\mathrm{eff}} \left(\frac{(\mathrm{Tlc}+273)^4}{\mathrm{Tlc}-\mathrm{Tsky}} - \frac{(\mathrm{Tsky}+273)^4}{\mathrm{Tlc}-\mathrm{T}} \right) \quad (4.50)$$

$$h2r = 5.67 \times 10-8 \times 0.11 \left(\frac{(60+273)^4}{60-26} - \frac{(26+273)^4}{60-21} \right) = 2.4\ \mathrm{W/m2k}\ \backslash$$

4.2.5. Overall Heat Transfers from Baking Pan to Ambient

The total effective top heat transfer coefficient from the baking pan surface to the ambient is U_t,is given as;

$$\mathrm{Ut} = \left[\frac{1}{\mathrm{h1}} + \frac{1}{\mathrm{h2}} \right] - 1 \quad (4.51)$$

Where, h_1 and h_2 are the heat transfer due to convection as well as the equivalent radiation heat transfer from the pan surface,

$$\mathrm{h1} = h1lc + \mathrm{h1r} \tag{4.51a}$$

$$h_1 = 1267.15\, W/m^2k + 1.62\, W/m^2k$$

$$h_1 = 1268.7\, W/m^2k$$

$$\mathrm{h2}=\mathrm{h2lc} + \mathrm{h2r} \tag{4.51b}$$

$$h_2 = 32.74\, W/m^2k + 2.314\, W/m^2k$$

$$h_2 = 35.054\, W/m^2k$$

Then, the total effective top heat transfer coefficient from baking pan surface to theambient is determined as:

$$\mathrm{Ut} = \left[\frac{1}{1268.7} + \frac{1}{35.054}\right] - 1 = \ 34.01\ \mathrm{W/m2k}$$

By using the overall top heat transfer coefficient determine the rate of heat transfer (Q_t) from the baking pan to the ambient per unit area.

$$\frac{\mathrm{Qt}}{\mathrm{A}} = \mathrm{Ut}(\mathrm{Tp} - \mathrm{Tli}) \tag{4.52}$$

$$Q_t = 34.01(200 - 60)$$

$$Q_t = 4420.3\, w/m^2$$

Where, T_p is the average temperature of pan surface (200 ℃) and $T_{li}$is the temperature of lidpan cover (60 ℃).

Use the formula below to determine how much energy was used during the baking pan's heating process and the ensuing injera baking cycle. Some of the heat lost through the baking pan to the atmosphere may be absorbed by the product.

$$Qt = Ut(Tp - Tli) \times \text{A} \qquad (4.53)$$

$$\text{Qt} = 4421.3 \text{ w/m2} \times \frac{\pi d^2}{4}$$

Where d is the diameter of baking Mitad which is 58mm=0.58m

$$\text{Qt} = \ 4421.3 \frac{\text{w}}{\text{m2}} \times \ \frac{\pi 0.58^2}{4} = 12.5\, W$$

4.3. Determined Parameter

Table 4.5 Parameter for an improved aluminum biogas burner

Parameters	Symbols	Calculated value	Units	Equation number
The amount of power needed to bake a given dough	P_{out}	355	KJ	4.1
The amount of energy needed tobake an Injera at an estimated time	E	1.37	W	4.2
The required input power from flame combustion	$P_{required}$	2.62	KW	4.4
Biogas flow rate	Q_{biogas}	0.387	m^3/hr.	4.5
Density of biogas	ρ_{biogas}	0.94	kg/m3	4.11
Specific gravity of biogas	S	0.94	-	-
Diameter of jet orifice	d_j	3.9	mm	4.13
Area of jet orifice	A_j	20	mm^2	4.15
The velocity of gas in the orifice	V_o	0.7	m/s	4.16
The diameter of throat	d_t	20	mm	4.17

Area of throat	A_t	314	mm^2	4.18
Length of mixing chamber	L_m	300	mm	-
The velocity of gas in throat	V_t	0.0437	m⁄s	4.19
The pressure of gas in the throat	Pt	99.99×10^3	pa	4.20
The flow rate of the mixture in the throat	Q_m	0.000349	m3/s	4.21
Reynold number	R_e	0.036	-	4.23
The pressure drops in throat	ΔP	0.383	pa	4.24
The total number of ports required`	n_p	352	-	4.28
Flame height	H_f	4.3	mm	4.30
Average mean temperature between lid cover and baking pan	ΔT	130	℃	4.38
The Rayleigh number for baking pan and lid cover	R_a	2.558×10^9	-	4.38
An estimated lid pan temperature	T_{lc}	60	℃	4.38
The convectional heat transfercoefficient between baking pan Baking pan and lid cover	h_{1lc}	1302	W/m^2K	4.39
Nusselt number for upper heated surface of baking pan	Nu	1302	-	4.40
The convectional heat transfercoefficients from lid cover to ambient	h_{2lc}	110	W/m^2K	4.44

4.4. Cost Analysis

The cost needed to manufacture an improved biogas fueled aluminum burner is listed below;

Table 4.6 Initial expenditure to manufacture an improved aluminum burner

Initial expenditure to manufacture an improved aluminum biogas burner					
S.N	**Items**	**Unit price in ETB**	**Units**	**Quantity**	**Size**
1	Mild steel	1000	Pcs	1	-
2	Round bar	800	Pcs	1	Ø2cm
3	Galvanized Sheet	600	Pcs	1.5	-
4	Sheet Metal	2000	Pcs	1	-
5	Aluminum scrap	30	kg	10	-
6	Electrode	1000	Packet	1	Ø2.5 ×500
	Operation				
7	Casting	250		4	Ø12cm
8	Cutting	200		1	
9	Painting	100		1	-
10	Baking Pan	300		1	Ø56
11	Valve	100		4	-
12	Orfice Plate	50		4	Ø2cm
13	Labor cost	1000		1	
14	Total cost of selling an improved aluminum biogas injera baking stoves 9200 ETB				

CHAPTER FIVE

5. EXIPERMENTAL SETUP PREPARATION AND DEVELOPMENT

Throughout the development of an improved aluminum biogas burner, the features that were previously defined are fully utilized and produced. The burner and its part is manufactured by the Manufacturing Technology and Engineering Industry Research Development Center Manufacturing shop. This section provides a quick rundown of the tools and supplies required to manufacture this burner and its parts.

5.1. Materials

- Aluminum Scrap

Scrap aluminum was used to produce burner head

a) Collected aluminum b) cutting in to smaller piece

Figure 5.1 Aluminum scrap preparation

- Foam board

Foam is Material used to prepare pattern which is used to produce the real aluminum

a) Smaller size b) Medium size c) larger size

Figure 5.2 Pattern development

Figure 5.3 Assembled pattern

- Sand and Bentonite

Sand and bentonite is used to prepare mold in different diameter of aluminum

Sand and bentonite preparation a) pure sand and bentonite b) remove the dust and mix

Figure 5.4 Sand and Bentonite preparation

- Flat Iron and Mild Steel

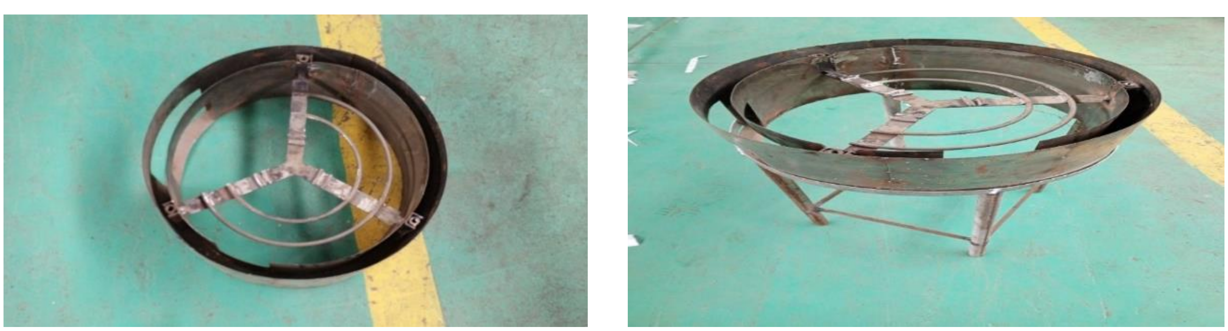


Figure 5.5 Combustion chamber

- Galvanized Sheet

Figure 5.6 Pan cover construction

5.2. Process of Manufacturing

Pattern Development

- Mold Preparation and Casting Process

Figure 5.7 Mold preparation

- Aluminum Melting Process

Figure 5.8 Aluminum melting

- Pouring Process

Figure 5.9 Prepare aluminum by cast

- Assembled Cast Aluminum

Figure 3.10 Assembled cast aluminum

- Machine Operation

Figure 5.11 Operation on lath machine

- Drilling the Flame Ports

Figure 5.12 Drill the flame port

- Internal Parts of the Burner Head

Figure 5.13 Internal parts of burner head

- Assembled Burner Head with Channel

Figure 5.14 Assembled burner head with channels

Parts of injera baking stove without cover and clay pan

Figure 5.15 parts of biogas baking stove

5.3. Experimental Set Up

All parts of injera baking stove is clearly observed and does not take much space to operate the overall space required for such is design is very small as compared to previously constructed biogas injera baking stove one. The assembled parts of biogas fueled injera baking mitad is found below;

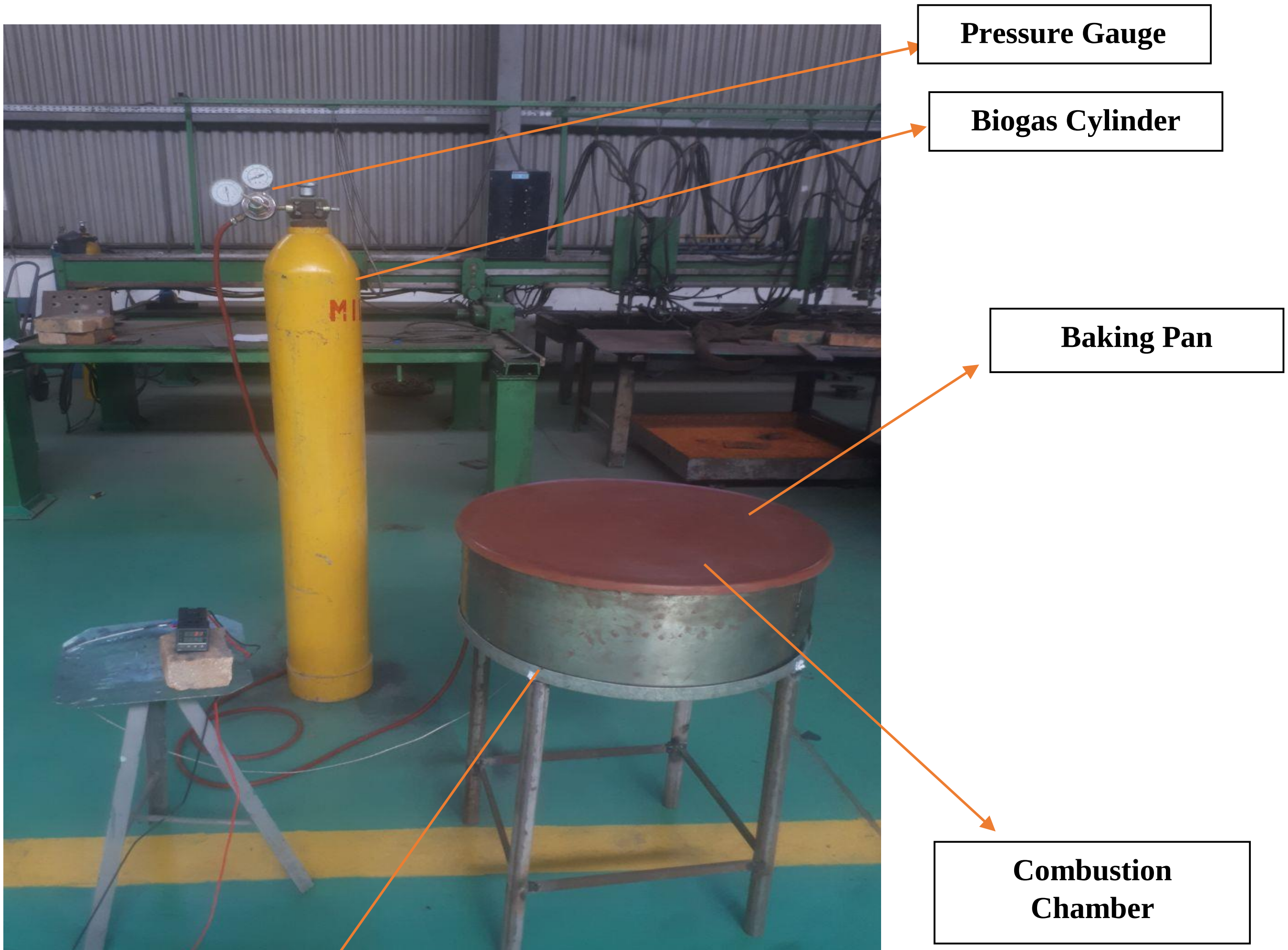


Figure 5.16 The outer parts of baking stove

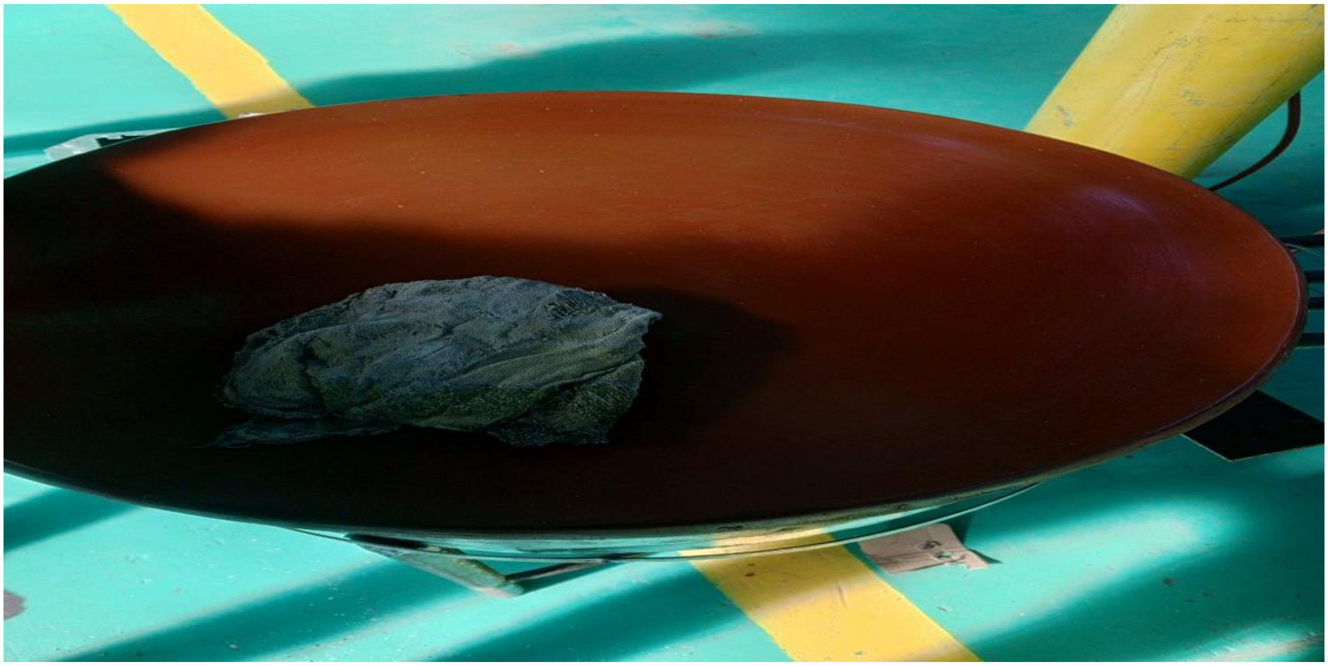


Figure 5.17 Sweeping the pan surface

Figure 5.18 Pouring the Dough

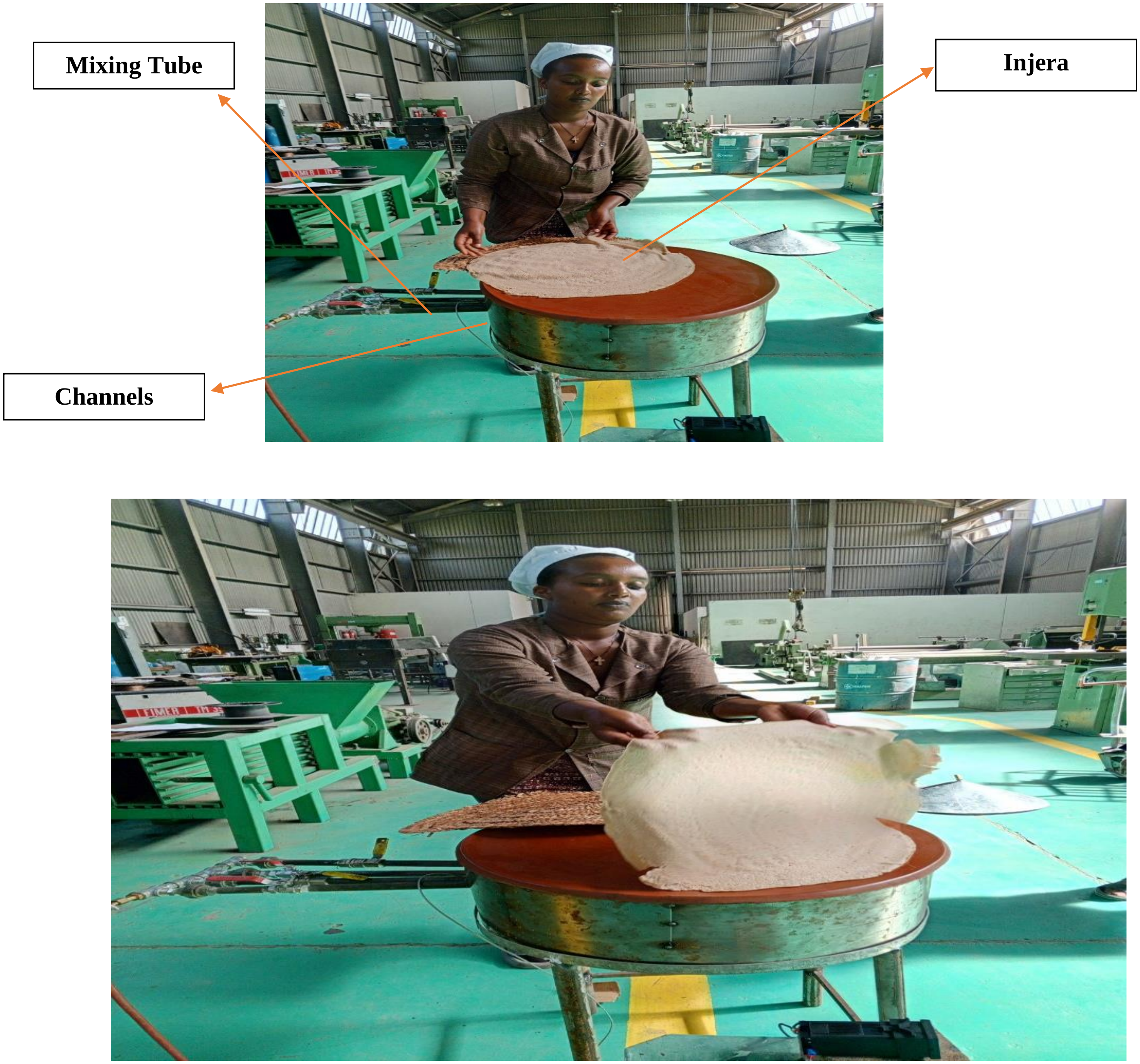


Figure 5.19 Take off injera

CHAPTER SIX

6. EXPERIMENTAL TEST RESULT AND DISCUSSION

In this section, the experimental test results for the newly built biogas injera baking stoves are addressed and presented in tabular and graphical form. The experimental test result revealed that the newly developed biogas injera baking stoves show stunning performance. The key performance indicators for the newly built biogas injera baking stoves were temperature, cooking time, biogas consumption, efficiency, amount of energy required, and injera quality during the experimental test.

6.1. Performance Evaluation Parameter and its result During Baking Process

The primary factors used in this study to assess the effectiveness of the biogas injera baking stove are temperature distribution, cooking time, quantity of biogas consumed, injera quality, amount of energy required, and stove efficiency.

- **Instrument Calibration Techniques**

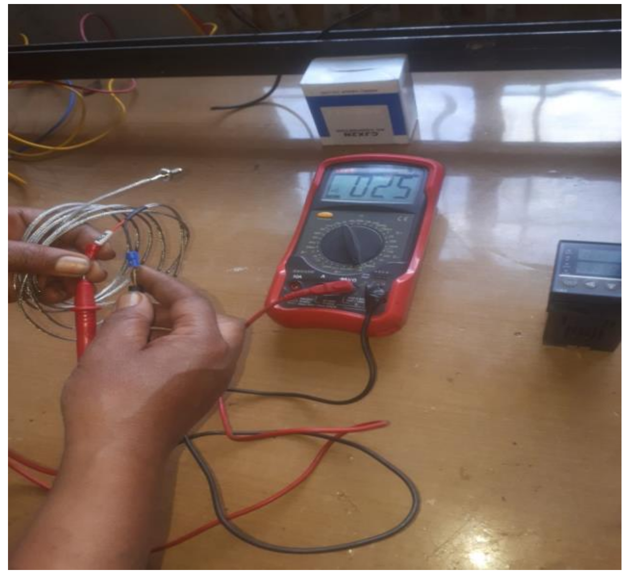
Before conduct any experiment on baking pan, injera, and combustion chamber, calibration is a must. the K- type thermocouple by connecting it to a digital multi meter to check its continuity. These activities captured by photo below;

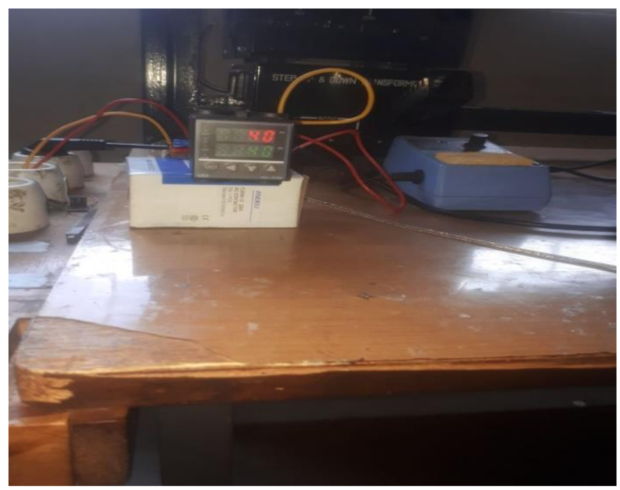
Thermocouple calibration

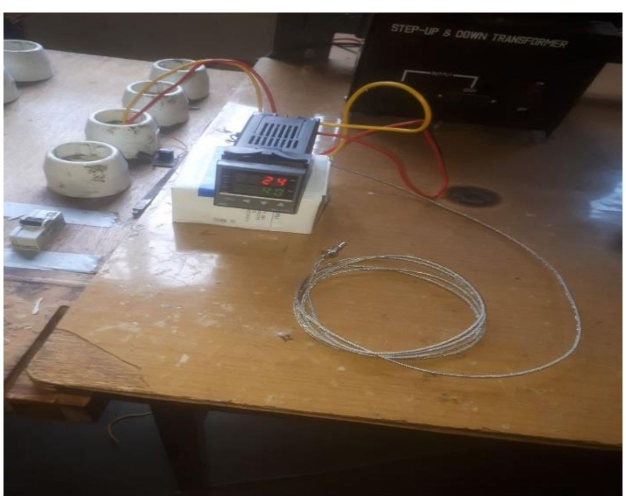
K-type Thermocouple

Digital Multimeter

Continuity check







6.1.1. Temperature Distribution

The temperature distribution within the baking pan of the new biogas injera baking stove was measured and recorded at five different spots, namely the south, north, middle, east and west directions of the baking pan, using an infrared thermometer. The temperature of the baking pan before it was lit on fire, the temperature of the pan after it has baked the injera, the temperature of the injera during baking, and the temperature of the pan after it has been baked are all measured in five different directions. During the baking process, the temperature of combustion was monitored using K-type thermocouples connected with digital temperature recorder.

- **Temperature**

Instant temperature of batter at pouring

The temperature of the baking Injera dough is measured five time at their rounds. Thetemperature of the batter is very close each other at different locations. In Figure below shows thatthe temperature of Injera is uniform and the Injera baking pan also. The baking temperature should be uniform and this helps to find out the texture of Injera is as need and hit the target. The temperature of Injera at instant of pouring is measured in five round at specified place andthe average temperatures are shown

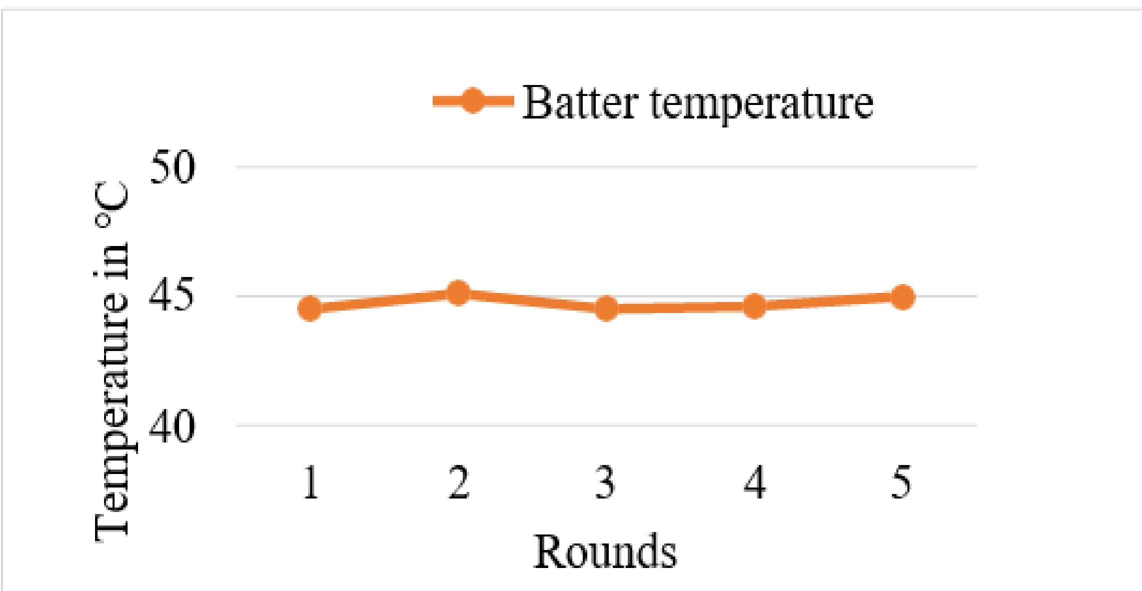


Figure 6 batter temperatur

1. Initial temperature of baking pan before ignited

Figure 6.1 Labeling the direction

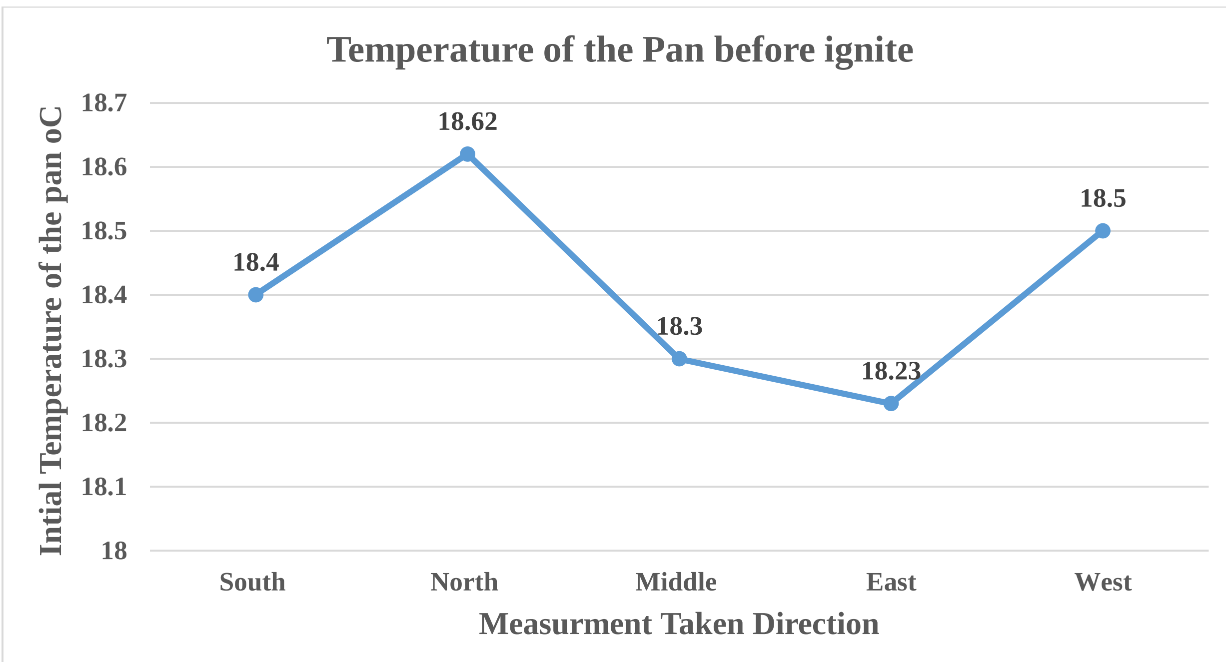


Figure 6.2 Initial temperature of the before ignited

The preceding figure5.18 illustrates how an infrared thermometer was used to measure the injera baking pan's initial temperature prior to the burner igniting. The test was carried out on the pan's front face, and the temperature was recorded in five different directions: south, north, middle, east and west. Because of the meteorological conditions throughout the test runs, the temperature distribution over this baking pan was extremely similar in terms of numerical value.

2. Baking temperature of pan before baking injera

The baking pan's heating temperature was tested at five different angles, including the south, north, east, middle, and west, before the dough was placed within. Using an infrared thermometer, the temperature was determined.

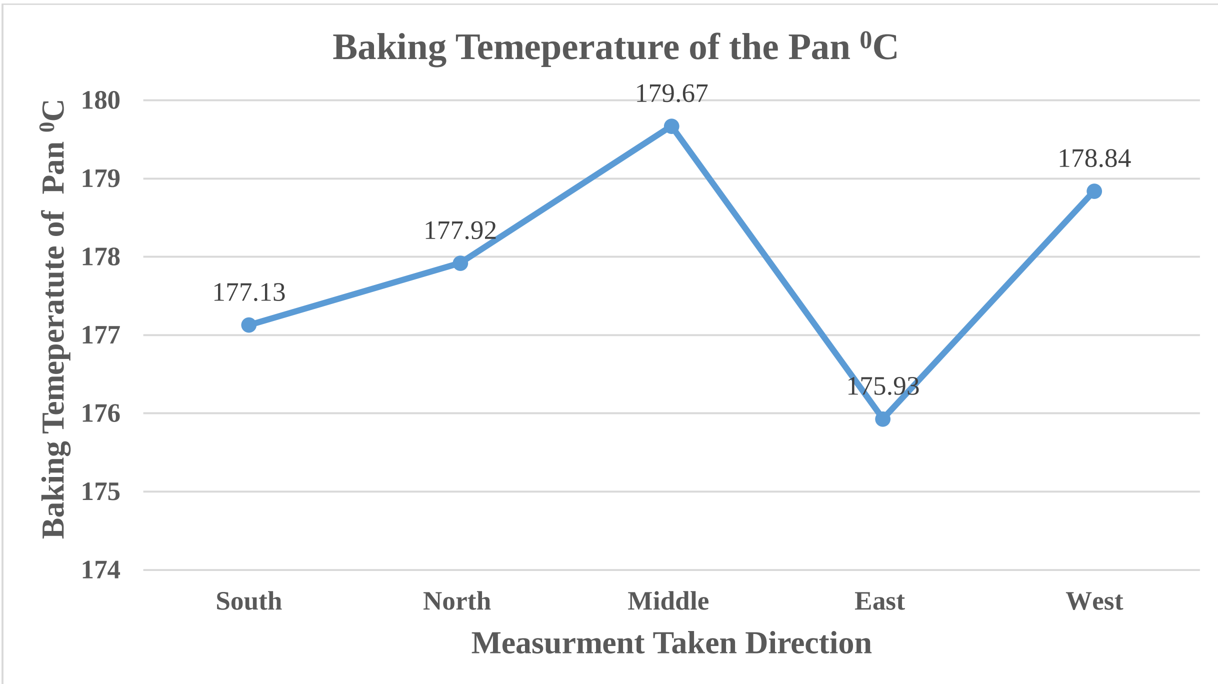


Figure 6.3 Baking temperature of the pan

The experimental tests of above figure 5.19 illustrates how the pan's heating temperature was monitored and recorded at five different baking pan orientations, including the south, north, middle, east, and west. The newly built biogas injera baking burner demonstrated uniform heat distribution over the baking pan's surface based on the results of testing.

Temperature of the pan at the center

In figure below shows that the temperature reading of the baking pan center for different period of time and, as the graph shows that the temperature of the baking pan at the center increases gradually as the time goes and the heating power.

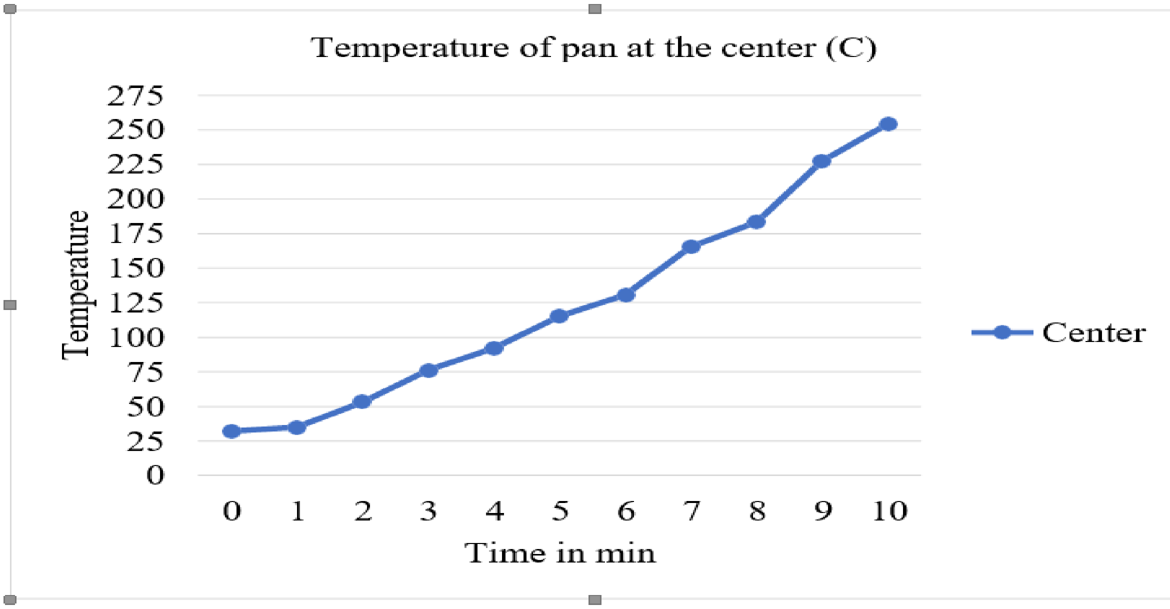


Figure 6.3 Temperature of the pan at the center

3. Temperature of injera during baking

Injera's temperature was also recorded at five different baking pan orientations, including the south, north, middle, east, and west. On the recently created biogas injera baking ovens, the experiment was carried out.

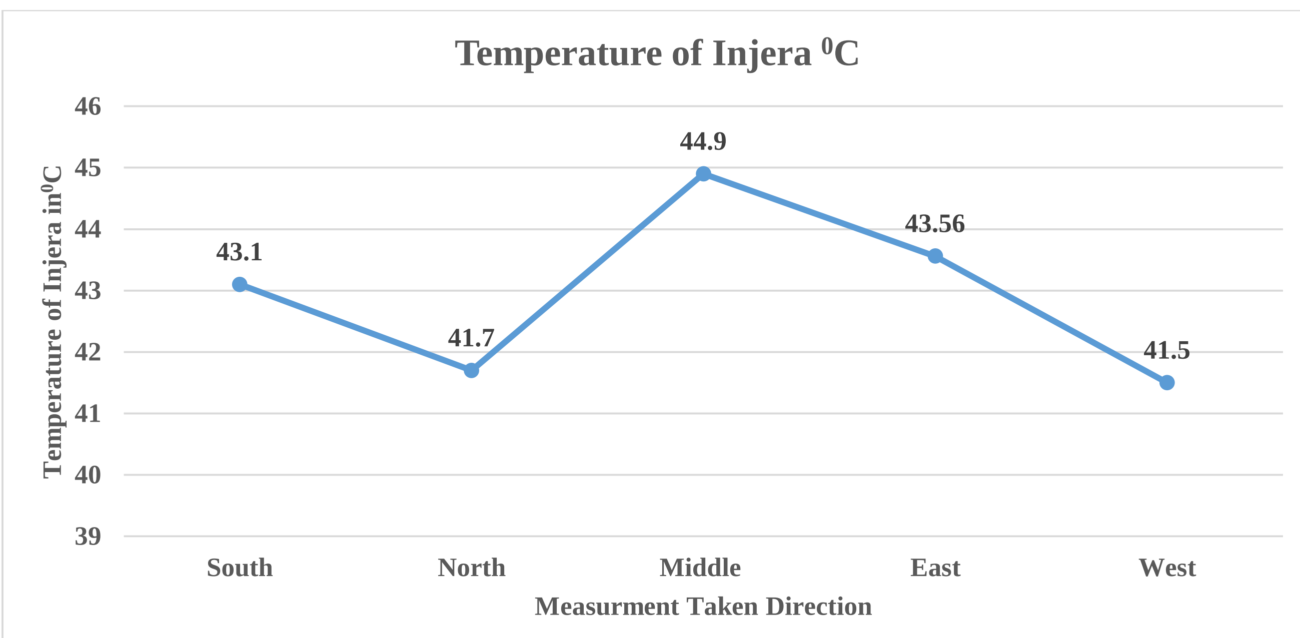


Figure 6.4 Temperature of injera

The following graph illustrates how an infrared thermometer was used to measure the temperature of injera baked on the recently invented biogas injera baking burner. On the recently created biogas injera baking stove, the experimental test result revealed that the injera's temperature in the middle of the baking pan was greater than the injera's temperature in the remaining directions.

4. Temperature of injera after baking

The temperature of injera after baking also recorded at five spots south, north, middle, east and west.

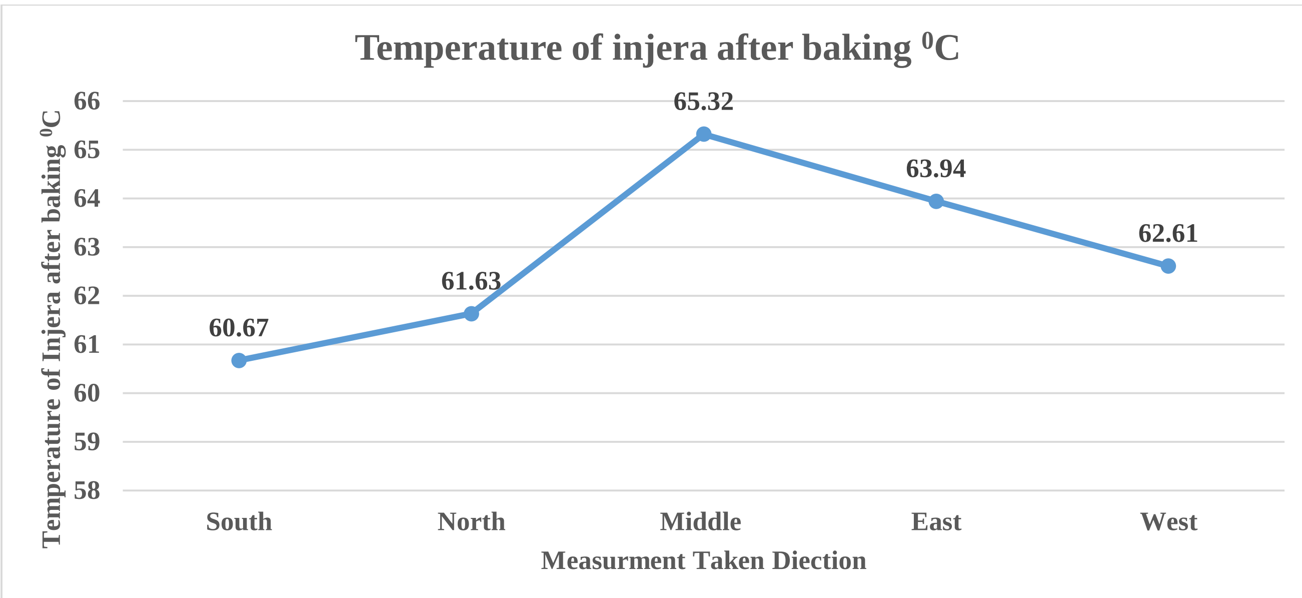


Figure 6.5 Temperature of injera after baking

After baking, the temperature of the injera is displayed in Figure 5.21. The aforementioned graph illustrates that the injera baked on the newly developed biogas injera baking stove had nearly constant temperature throughout, and that the injera's quality was superior to that of the previous model.

5. Combustion Temperature

The combustion temperature of the burner was obtained by placing K-type thermo couple sensor in the wall of combustion chamber. The combustion temperature measured in every five minute This K – type thermo couple was connected with Temperature reader. The value obtained from the reader is listed below;

Figure 6.6 Combustion Temperature recording

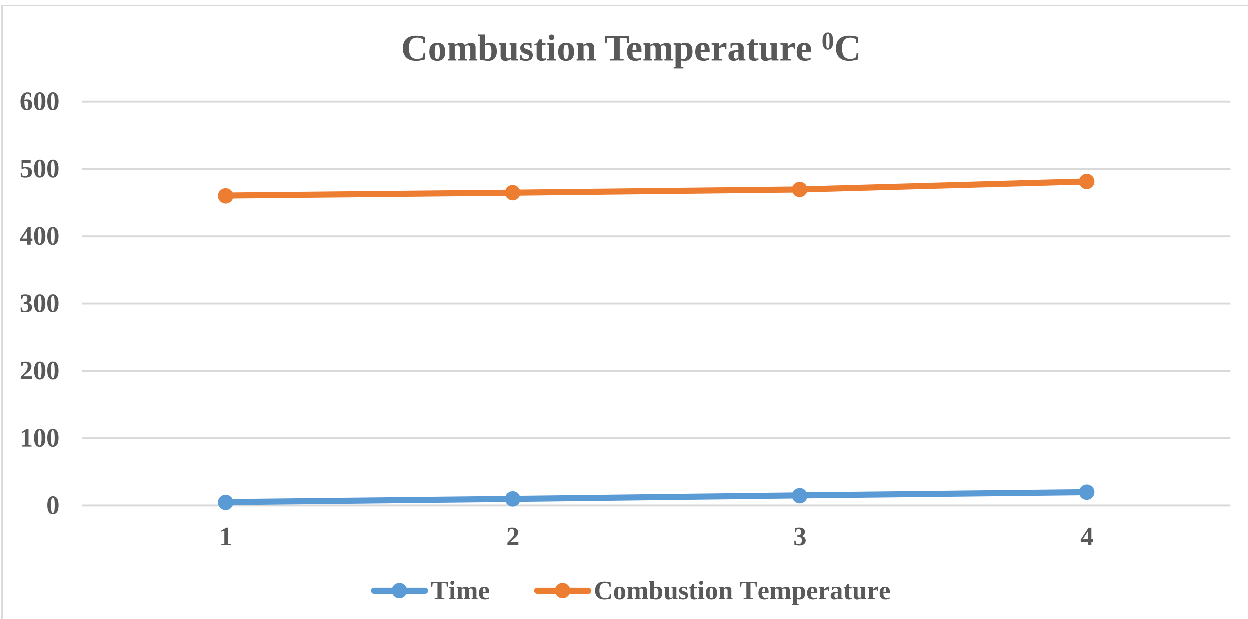


Figure 6.7 Combustion Temperature

Measurement equipment-measured combustion temperature is shown in Figure 5.22. A K-Types thermocouple attached to a temperature reader was used to test the combustion temperature of the recently constructed biogas injera baking stove, as the above image illustrates. Nearly identical outcomes were obtained with this apparatus. More heat was generated during combustion in the recently designed biogas stove compared to the earlier model.

Outside body temperature combustion chamber with time

The combustion chamber is molded using ash to gypsum ratio by mass. And the temperature distribution from the inside of chamber to outside is very slow and heat dissipation to the surrounding reduced by the insulator during baking an Injera. The temperature is measured by using a device what call it Digital thermometer.

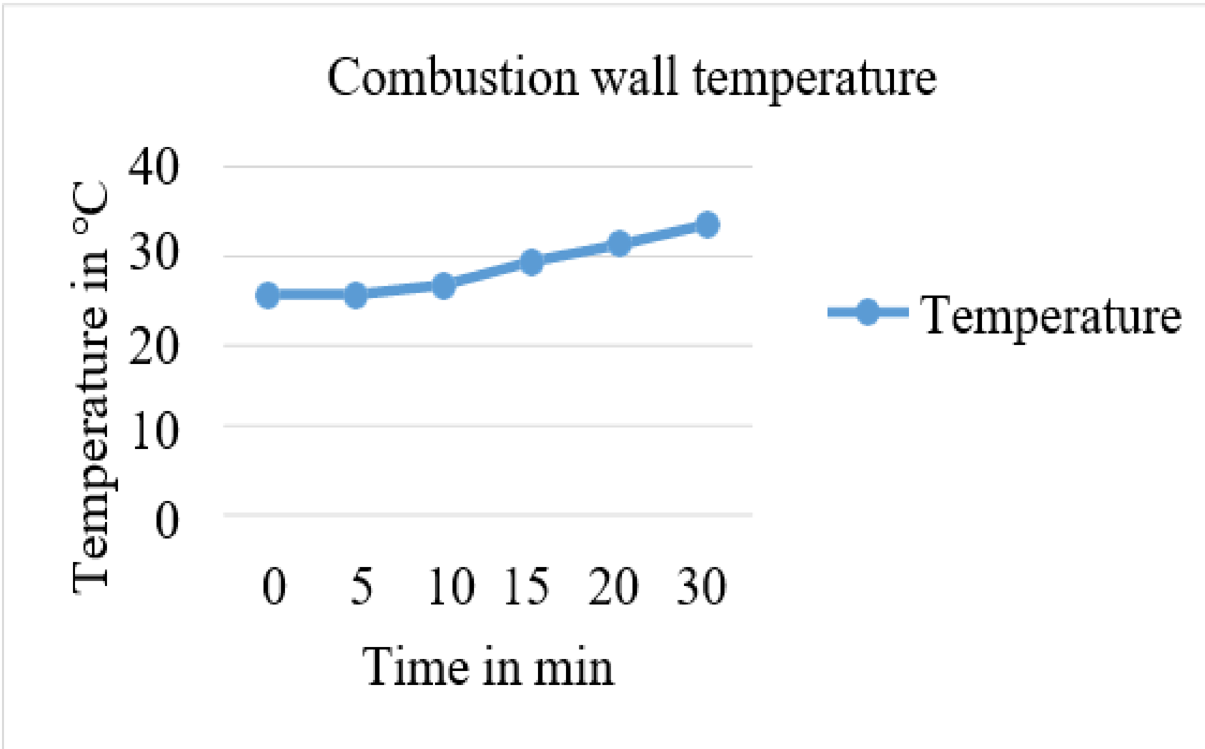


Figure 6.8 Combustion wall temperature

6. Comparison of the old temperature distribution with the new one

New biogas injera baking stove temperature distribution

Temperature Distribution	¤ Average Minimum Temperature(°C)	Direction	Average Maximum Temperature(°C)	Direction
Initial temperature of baking pan before ignition	18.23	east	18.62	North
Baking Temperature of Pan	175.93	East	179.67	Middle

Temperature of Injera During Baking	41.5	west	44.9	Middle
Temperature of Injera After Baking	60.67	south	65.32	Middle
Combustion temperature	460.43	-	481.6	-

Old biogas injera baking stove temperature distribution

Temperature Distribution	Average Minimum Temperature(°C)	Direction	Average Maximum Temperature(°C)	Direction
Initial temperature of baking pan before ignition	17.2	south	17.56	North
Baking Temperature of Pan	173.6	south	178.5	Middle
Temperature of Injera During Baking	40.9	west	43.26	Middle
Temperature of Injera After Baking	61.5	south	63.1	Middle
Combustion temperature	331.5	-	478.75	-

From the above data table, we can conclude that the temperature distribution of the newly developed biogas injera baking burner better than the previously developed biogas injera baking burner.

6.2. Cooking Time

From startup until the first Injera being baked, the cooking time indicates how long it took. More care and attention should be given to the startup phase in particular. since fuel is used and time is lost when there is a delay in starting up. Since there are two rounds to measuring cooking time, the first round is recorded on the first day, and the second round is recorded on the second day. The baking time of injera baking stove is listed below;

Early baking time of injera (Keresemua, 2023)

Activities	Time (min)	Time (min)	Time(min)
	1st round	2nd round	3rd round
Start-up time	8.6	8.54	8.59
Pouring a single Injera	0.17	0.17	0.17
Take off Injera	0.85	0.85	0.85
Sweep pan	0.17	0.17	0.17
Injera baked	1.6	1.62	1.6
Total cooking time	11.39	11.31	11.33

Table 6.6 New Baking time of injera

List of activities	Time(min)	Time(min)
Start-up time	9	8.7
Pouring time	0.19	0.16
Injera removing time	0.89	0.192
Sweep the pan	0.14	0.17
Injera baked	1.57	1.67
Total cooking time	11.79	10.792

When it is compared, the newly developed biogas stove cooking time is compared with the old biogas stove cooking time. The newly developed biogas stove took 1.57 minutes to bake a single injera as compared with the old one, which took 1.6 minutes to bake a single injera.

The newly developed biogas fueled injera baking stove showed better performance than the previous one.

6.3. Biogas Consumption

The amount of biogas consumed to bake single injera on the newly developed biogas injera baking stove is 1.7 litter. This gas consumption value is obtained by using an instrument is called gas flow meter which is taken from ministry of water and energy. The amount of gas consumed by this injera baking stove is relatively better than the existing one which will use two point five (2.5) litter to bake a single injera.

6.4. Thermal Efficiency

The burner thermal efficiency tested by biogas. And the thermal efficiency of the biogas stoves is determined according to the physical and thermal properties of biogas. The thermal efficiency of the Injera baking stove using methane gas is 52.5 %. The efficiency is good and attractive. This injera baking stove found to be efficient compared with other biomass cooking stove which is listed below;

Table 6.7 Biomass injera baking stoves

S.N	Biomass injera baking stoves	Thermal efficiency(%)
1	Efficient three stone	8-12
2	Efficient Mirt injera stove	16-21
3	Gonzie	23-27

The efficiency increment is because the works contain asbestos for the wallof the combustion chamber and flame ports puncturing arrangement in equal transversal and radial distances.

$$\eta\text{thi} = \frac{(\text{MmCm}+\text{MiCi}+\text{MwCw})\ (\text{Tf}-\text{Ta})\text{LwMw}}{\text{VbiogasCVbiogas}} \times 100\% \qquad (4.54)$$

Where, M_m and C_m: the mass and specific heat capacity of injera baking pan, 4.0 kg and 1.35KJ/kg℃M_i and C_i: mass and specific heat capacity of baked Injera, 0.325kg and 1.65kJ/kg℃,

M_w and C_w: mass and specific heat capacity of water in dough, 0.486kg and 4.19 kJ/kg℃,

T_f and T_a: initial temperature of pan and final of water 25.5℃ and 94.3 ℃,L_W: latent heat vaporization of water, 2260KJ/kg,

M_W: mass of water in dough, 0.3084kg

T_{wi}: initial temperature of water, 29.6℃

V_{biogas}: 0.064 $m^3$of biogas.

CV_{biogas}: the average calorific value of biogas is 39.8MJ/m^3

The thermal efficiency of this biogas injera baking stove is 52.5 %.

$$\eta thi = \frac{\left(4.0\text{ kg} \times \frac{1.35\text{KJ}}{\text{kg}}{}^{\circ}\text{C} + 0.325\text{kg} \times 1.65\frac{\text{kJ}}{\text{kg}}{}^{\circ}\text{C} + 0.486\text{kg} \times 4.19\text{ kJ/kg}{}^{\circ}\text{C}\right)(94.3-25.5)2260\text{KJ/kg} \times 0.3084\text{kg}}{0.064\text{ m3} \times 39.8\text{MJ/m3}} \times 100\% = 0.525 = 52.5\%$$

6.5. Texture of Injera

According to Ethiopian standard agency injera standards, the largest size that can be accepted is 52 cm. According to ESA (2012), the Injera should have a bubbly eye on the upper side and a smooth back. Equal temperature is necessary for the texture of injera; otherwise, both its upper and lower portions are unpleasant and bad for apatite. Additionally, as seen in Figure photograph, this injera has a smooth back side and a good bubbly eye, measuring 52 cm in diameter.

Early biogas Injera Textures

Front

Back

New Biogas Injera Textures

Figure 6.8 Texture of new injera baked

When compared to the texture of injera, the one that was backed by previous biogas injera baking stoves has no more spongy eyes on the top surface. This indicates that the heat distribution through out of the baking pan is poor compared with the recently developed biogas baking stoves, which have more bubbly eyes on the top surface and smooth at the back.

6.6. Exergy Analysis

Exergy analysis is a practical method for evaluating the advantages of energy distribution or conversion systems or processes. Energy needs to be used efficiently in order to reduce energy losses and maximize a system's useable work output. By taking into account the irreversibility and inefficiencies associated with energy conversion processes, exergy analysis helps identify areas for improvement and help optimize energy use.

An overall exergy balance for the system can be written as;

Exergy input – [Exergy recovered + Exergy loss] - Exergy consumption = Exergy accumulation
Exergy input is given as

$$Exin = mbCb\left(1 - \frac{Ta}{Tbiogas}\right) \times \ Xc \tag{4.55}$$

Where: m_b: mass of biogas, 0.08kg, because 1cubic meter of biogas is 1.25kg of biogas.

T_a: ambient temperature, 25.5℃

$Tbiogas$: biogas temperature (the flame temperature of biogas can range from around 1,970 to 2,060 degrees Celsius), let's take 2000℃.

c_b: calorific value of biogas, 39.8 MJ/m^3, 1 joule per cubic meter of biogas is equivalent to 0.7 joules per kilogram, which is equivalent to 27.86 MJ/kg.

x_c: theoretical combustion efficiency of biogas, 90%.

$$\text{Exin} = 0.08\text{kg} \times \frac{39.8\text{MJ}}{\text{m3}}\left(1 - \frac{25.5}{2000}\right) \times \ 0.9 = 2829\text{KJ}$$

Biogas containing high levels of methane can theoretically have a combustion efficiency of 100%, meaning that all of the energy included in the biogas is converted to heat. But in practical terms, partial combustion, heat losses, and other limitations make it difficult to achieve 100% combustion efficiency.

The equipment used for combustion, the environment in which it operates, and the layout of the system all affect how efficiently biogas burns. Biogas combustion efficiency may typically be achieved by contemporary combustion systems within the range of 90% and 95%.

The exergy output is given as below;

For injera baking Stove

$$\mathrm{Exois} = \mathrm{mwCpw(Tfw - Tiw)}\left(1 - \frac{\mathrm{Ta}}{\mathrm{Tfw}}\right) + \mathrm{mbCpb(Tfb - Tb)}\left(1 - \frac{\mathrm{Ta}}{\mathrm{Tfb}}\right) + \mathrm{mdCpd(Tfd - Tid)}\left(1 - \frac{\mathrm{Ta}}{\mathrm{Tfd}}\right) \quad (4.56)$$

Where; m_w, m_{pot}, $m_b and\ m_d$: the mass of water, baking pan and dough, (for 0.486 for dough), 4.0 kg and 0.581kg respectively.

c_{pw}, $cpb\ and\ cp_d$: the specific heat capacity of water, baking pan and

dough respectively.

T_w, Tb, $T_a and\ T_d$: the temperature of water, baking pan, ambient and dough respectively.

Cp_b= 1.35KJ/kg℃ specific heat capacity of baking pan

Exergy efficiency, φ (%) defined as availability efficiency or second-law efficiency, quantifies the proportion of a system's useable or available work output to its total exergy input, is given as;

$$\varphi = \frac{\mathrm{Exo}}{\mathrm{Exin}} \quad (4.57)$$

The exergy efficiency for injera baking stove is 76 %.

- The initial temperature of dough is 26.5 ℃ and final injera temperature is 200.67℃.
- The initial temperature of water is 26.5 ℃ (for mixed with teff) and final (boiling temperature) is 94.29℃.
- The initial temperature of baking pan is 30 ℃ and final temperature is 180 ℃.
- The ambient temperature is 25.69℃, when this measurement is performed.

- **Sensitivity Analysis**

Basic Concept

ingredients of a sensitivity analysis are the model's uncertain input factors and model's outputs. Here and in the following we shall interpret as factor all that can be plausibly changed at the level of model formulation or model input in the quest to map the space of the model predictions. thus a factor could be an input datum acquired with a known uncertainty, as well as a parameter estimated with known uncertainty in a previous stage of modeling, as well a trigger acting on the model's structure (e.g. Ameshsize choice), or a trigger selecting the choice of a model versus another, or the selection of a scenario. Modelers usually have considerable latitude of choice as to how to combine factors in a sensitivity analysis, e.g., what to vary, what to keep fixed. Also a modeler's choice is, to some extent, whether to treat factors as dependent upon one another or as independent. the design and the interpretation of this ensemble of the model simulations constitute a sensitivity analysis(www.sensetivity analysis).

Use of sensitivity analysis

Sensitivity analysis is a tool to test the quality of a model or better the quality of an inference based on a model. This is investigated by looking at the robustness of an inference. there is a trade of here between how scrupulous an analyst is in exploring the input assumptions and how wide the resulting inference will be(www.sensetivity analysis).

Methodology of the sensitivity analysis

The sensitivity analysis is done using simple linear differentiation methods by changing one parameter only and measuring its effect on the FTF delay. Tables 3 and 4 summarize the DNS used to estimate the sensitivity of FTF phase. The extreme values retained for the parameters match their estimated uncertainty. For each set of parameters, a steady state is first computed leading to cases called B1 to B10 for the Boudy case and K1 to K10 for the Kornilov configuration. Then, all Bi and Ki are pulsated at several frequencies. Finally, for each frequency, sensitivities are obtained from differentiations formula given in Table.

Computational parameters for sensitivity analysis of FTF for the Kornilov configuration. Bold characters indicate changes with respect to K1 case.

Case	s_L (300 K) (cm/s)	α (°)	T_a (K)	T_d (K)	T_w (K)
K_1	27.4	0	293	373	373
K_2	**24.9**	0	293	373	373
K_3	**29.5**	0	293	373	373
K_4	27.4	0	283	373	373
K_5	27.4	0	303	373	373
K_6	27.4	0	293	**293**	**323**
K_7	27.4	0	293	**293**	373
K_8	27.4	0	293	**293**	**423**
K_9	27.4	**5**	293	373	373
K_{10}	27.4	**10**	293	373	373

6.7. Experimental Result Summary

Prototypes are constructed using the most efficient manufacturing procedures in order to acquire design analysis results during experimentation. In order to reduce heat loss to the environment, asbestos is used to mold the wall of the combustion chamber. Additional aeration for the fuel is employed by drilling rectangular holes in the stove's side. An infrared thermometer is used to test the temperature of the baking pan in four directions prior to baking the injera, and a K-type thermocouple is used to measure the temperature of the combustion chamber. Additionally, a stopwatch is used to record how long it takes to bake one injera, polish its surface, and remove it. The Injera baking stove control cooking test method was applied. The thermal efficiency of baking stove found to be 52.5 %.

CONCLUSION AND RECOMMENDATION

CONCLUSION

The goal of this research is to investigate a biogas stove through experimentation in order to bake injera. Both the price of wood and baking time are decreased with the use of this paper. Additionally, the wood smoke produced by this stove's construction lowers carbon dioxide emissions into the atmosphere. This lessens the need for wood and the destruction of forests, slowing the advancement of global warming. This burner design idea and parameter investigation techniques make a difference in people life by bring a uniform heat distribution throughout the baking pan.

Because of its round form, the burner head designed for Injera baking facilitates easy air-fuel mixture flow. The primary benefits of the experimental test were the ability to assess the biogas Injera baking stove's performance in terms of cooking time, biogas consumption, temperature, efficiency, energy requirement, and Injera quality. An infrared thermometer is used to measure temperature in four directions at equal radial distances. The portion of the Injera baking stove with a thermal efficiency of 52.5 %. According to the findings, baking an injera takes 1.57 minutes, and baking injera requires 1.7 m3 of biogas in stove parts.

As per the analytical design, several formulas were used to design the key parts of such design. On the circumfercial face of the burner there are four different diameter burner head. the one head with 117 mm diameter has 43 holes, the other head with 245mm diameter has 63 holes and the rest two burner head with 348 mm and 467mm have 103 and 139 holes respectively. The gap between each port is 9 mm. this geometric feature makes this injera making burner viable in all aspect.

RECOMMENDATION

To meet the ever-increasing demand energy of using alternative means, energy like biogas is a viable option, especially in rural areas of the country. In order to use the biogas generated from different wastes for injera baking purposes, using a biogas burner is a must. In this design, the burner head prepared by sand cast method from aluminum, which more prone to deformation due to low melting point So any researcher who has an interest in this work can make some modifications by mixing aluminum with other material such as copper. Again there is no use of software to show the movement of the flame escaping from the baking pan, so this helps to study further in this area.

REFERENCES

Abdella, T., Alemu, D., & Dino, K. (n.d.). *Experimental Investigation of Biogas Injera Baking Stove Using Circular Ring Pipe Burner*. https://doi.org/10.21203/rs.3.rs-3558204/v1

Adem, K. D., & Ambie, D. A. (2017). A review of injera baking technologies in Ethiopia: Challenges and gaps. *Energy for Sustainable Development*, *41*, 69–80. https://doi.org/10.1016/j.esd.2017.08.003

Alemayehu, Y. A. (2015). Status and benefits of renewable energy technologies in the rural areas of ethiopia: A case study on improved cooking stoves and biogas technologies. *International Journal of Renewable Energy Development*, *4*(2), 103–111. https://doi.org/10.14710/ijred.4.2.103-111

Ali, L. H., & Al-Ghannam, K. A. (1981). Investigations into asphaltenes in heavy crude oils. I. Effect of temperature on precipitation by alkane solvents. *Fuel*, *60*(11), 1043–1046. https://doi.org/10.1016/0016-2361(81)90047-8

Bajet, Jr., M. A., Paz, C. B., Bermio, J. B., Bajet, N. A., & Bajet, J. B. (2012). Modified Stove Burner for Biogas. *IAMURE International Journal of Mathematics, Engineering & Technology*, *4*(1), 33–47. https://doi.org/10.7718/iamure.ijmet.v4i1.418

Bantelay, D. T. (2014). Design, Manufacturing and Performance Evaluation of House Hold Gasifier Stove: A Case Study of Ethiopia. *American Journal of Energy Engineering*, *2*(4), 96. https://doi.org/10.11648/j.ajee.20140204.12

Bhandari, B., Lee, K. T., Lee, C. S., Song, C. K., Maskey, R. K., & Ahn, S. H. (2014). A novel off-grid hybrid power system comprised of solar photovoltaic, wind, and hydro energy sources. *Applied Energy*, *133*, 236–242. https://doi.org/10.1016/j.apenergy.2014.07.033

Bicks, A. T. (2020). Investigation of Biogas Energy Yield from Local Food Waste and Integration of Biogas Digester and Baking Stove for Injera Preparation: A Case Study in the University of Gondar Student Cafeteria. *Journal of Energy*, *2020*, 1–11. https://doi.org/10.1155/2020/8892279

Chandra, A., Tiwari, G. N., Srivastava, V. K., & Yadav, Y. P. (1991). PERFORMANCE

EVALUATION OF BIOGAS BURNERS. In *Energy Convers. Mgmt* (Vol. 32, Issue 4).

Chandra, A., Tiwari, I. G. N., & Yadav, Y. P. (1991). HYDRODYNAMICAL MODELLING OF A BIOGAS BURNER. In *Energy Convers. Mgmt* (Vol. 32, Issue 4).

Cheng, Y.-L., Lee, C.-Y., Huang, Y.-L., Buckner, C. A., Lafrenie, R. M., Dénommée, J. A., Caswell, J. M., Want, D. A., Gan, G. G., Leong, Y. C., Bee, P. C., Chin, E., Teh, A. K. H., Picco, S., Villegas, L., Tonelli, F., Merlo, M., Rigau, J., Diaz, D., … Mathijssen, R. H. J. (2016). We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %. *Intech*, *11*(tourism), 13. https://www.intechopen.com/books/advanced-biometric-technologies/liveness-detection-in-biometrics

Colorado, A., & McDonell, V. (2018). Emissions and stability performance of a low-swirl burner operated on simulated biogas fuels in a boiler environment. *Applied Thermal Engineering*, *130*, 1507–1519. https://doi.org/10.1016/j.applthermaleng.2017.11.047

Decker, T., Baumgardner, M., Prapas, J., & Bradley, T. (2018). A mixed computational and experimental approach to improved biogas burner flame port design. *Energy for Sustainable Development*, *44*, 37–46. https://doi.org/10.1016/j.esd.2018.02.008

Devi, S., Sahoo, N., & Muthukumar, P. (2019). Combustion of biogas in Porous Radiant Burner: Low emission combustion. *Energy Procedia*, *158*, 1116–1121. https://doi.org/10.1016/j.egypro.2019.01.276

Devi, S., Sahoo, N., & Muthukumar, P. (2020). Impact of preheat zone properties on the flammability limits of crude biogas combustion in a two-layer porous radiant burner. *Journal of Physics: Conference Series*, *1473*(1). https://doi.org/10.1088/1742-6596/1473/1/012033

Elkelawy, M., Abdel-Rahman, A., Abou-elyazied, A., & El-malla, S. (2022). Experimental investigation on emission and combustion characteristics of an industrial burner using biogas co-fired with diesel and biodiesel. *Egyptian Sugar Journal*, *19*(0), 29–43. https://doi.org/10.21608/esugj.2022.164403.1025

Examiner, P., Basichas, A., & Mccleary, A. (2004). *(12) United States Patent*. *2*(12).

Ferrer, I., Garfí, M., Uggetti, E., Ferrer-Martí, L., Calderon, A., & Velo, E. (2011). Biogas production in low-cost household digesters at the Peruvian Andes. *Biomass and Bioenergy*, *35*(5), 1668–1674. https://doi.org/10.1016/j.biombioe.2010.12.036

Frederiks, B. (2012). *Biogas tests with Elephant grass and Guatemala grass*. *31*(April), 1–3. http://fact-foundation.com/sites/default/files/library/documents/36._biogas_tests_with_elephant_grass_pennisetum_purpureum.pdf

Friedlingstein, P., O'Sullivan, M., Jones, M. W., Andrew, R. M., Hauck, J., Olsen, A., Peters, G. P., Peters, W., Pongratz, J., Sitch, S., Le Quéré, C., Canadell, J. G., Ciais, P., Jackson, R. B., Alin, S., Aragão, L. E. O. C., Arneth, A., Arora, V., Bates, N. R., … Zaehle, S. (2020). Global Carbon Budget 2020. *Earth System Science Data*, *12*(4), 3269–3340. https://doi.org/10.5194/essd-12-3269-2020

Fulford, D. (1996). Biogas Stove Design. *Biomass*, *August*, 1–21.

Gao, H., Qu, Z., Tao, W., He, Y., & Zhou, J. (2011). Experimental study of biogas combustion in a two-layer packed bed burner. *Energy and Fuels*, *25*(7), 2887–2895. https://doi.org/10.1021/ef200500j

Gebreyohannes Hiben, Y., Tesema, A., Gebreyohannes, Y., & Gebray, P. (2020). *Development of Briquette Based Injera Baking Stove*. https://www.researchgate.net/publication/347890226

Godoy, E., Camargo, J. R., Marcelino, M. A., & Silveira, J. L. (2012). Development of a burner to measure biogas generation. *WIT Transactions on Ecology and the Environment*, *157*, 501–512. https://doi.org/10.2495/AIR120441

Hosseini, S. E., & Wahid, M. A. (2015). Effects of burner configuration on the characteristics of biogas flameless combustion. *Combustion Science and Technology*, *187*(8), 1240–1262. https://doi.org/10.1080/00102202.2015.1031224

J.O, A., B.N, I., & J, U. (2020). Cooking Performance of a Developed Biogas Burner (Stove). *International Journal of Engineering Applied Sciences and Technology*, *04*(12), 11–16. https://doi.org/10.33564/ijeast.2020.v04i12.002

Jadhav, P., Jadhav, M. P., Sudhakar, P. D. S. S., Prof, A., Mumbai, N., Crce, F., & Bandra, M.

(2015). Analysis of Burner for Biogas by Computational Fluid Dynamics and Optimization of Design by Genetic Algorithm Biogas burner for optimum combustion without losses View project Analysis of Burner for Biogas by Computational Fluid Dynamics and Optimization of Design by Genetic Algorithm. In *INTERNATIONAL JOURNAL FOR RESEARCH IN EMERGING SCIENCE AND TECHNOLOGY* (Issue 2). https://www.researchgate.net/publication/280488863

Kaewpradap, A., Noppharatana, A., & Jugjai, S. (2017). Cellular premixed flames of synthetic biogas composition effects on flat burner. *Engineering Journal*, *21*(7), 415–425. https://doi.org/10.4186/ej.2017.21.7.415

Kanase-Patil, A. B., Saini, R. P., & Sharma, M. P. (2010). Integrated renewable energy systems for off grid rural electrification of remote area. *Renewable Energy*, *35*(6), 1342–1349. https://doi.org/10.1016/j.renene.2009.10.005

Kebede, D., & Kiflu, A. (n.d.). DESIGN OF BIOGAS STOVE FOR INJERA BAKING APPLICTION. In *International Journal of Novel Research in Engineering and Science* (Vol. 1, Issue 21). www.noveltyjournals.com

Keramiotis, C., & Founti, M. A. (2013). An experimental investigation of stability and operation of a biogas fueled porous burner. *Fuel*, *103*, 278–284. https://doi.org/10.1016/j.fuel.2012.09.058

Keresemua, Y. Z. (2023). *Design , Development and Experimental Investigation of Multi- purpose Biogas Stove Design , Development and Experimental Investigation of Multi- purpose Biogas Stove*.

Kurchania, A. K., Panwar, N. L., & Pagar, S. D. (2010). International Journal of Sustainable Energy Design and performance evaluation of biogas stove for community cooking application Design and performance evaluation of biogas stove for community cooking application. *International Journal of Sustainable Energy*, *29*(2), 116–123. http://www.tandfonline.com/action/journalInformation?journalCode=gsol20

M, Y. W. (n.d.). *PERFORMANCE ANALYSIS OF BIOGAS STOVES WITH VARIATIONS OF FLAME BURNER FOR THE CAPACITY OF BIOGAS 1 M3 / DAY* (Vol. 10). www.arpnjournals.com

Mahmoudi, Y., Sarras, G., Mendez, L. D. A., & Tummers, M. J. (2013). *Flame Structure and Stabilization Mechanism of Biogas Flame in a Jet-in-Hot-Coflow Burner*. *C*(September).

Milivojević, A. M., Adžić, M. M., Gojak, M. D., Stamenić, M. S., & AdŽić, V. M. (2021). Analysis of the Performance of a Low-Power Atmospheric Burner for Gas Appliances for Households and their Impact on the Emission and Stability of the Burner. *Thermal Science*, *25*(3), 1891–1903. https://doi.org/10.2298/TSCI200717302M

Mohammed, A. S., Atnaw, S. M., & Desta, M. (2023). The Biogas Technology Development in Ethiopia: The Status, and the Role of Private Sectors, Academic Institutions, and Research Centers. In *Lecture Notes in Energy* (Vol. 92, Issue November). https://doi.org/10.1007/978-981-19-6688-0_14

Mohammed, G. (2015). Biogas production from cow dung and food waste. *Global Journal of Pollution and Hazardous Waste Management*, *3*(1), 103–108.

Nega, D. T., Mulugeta, B., & Demissie, S. W. (2021). Improved biogas ‘Injera’ bakery stove design, assemble and its baking pan floor temperature distribution test. *Energy for Sustainable Development*, *61*, 65–73. https://doi.org/10.1016/j.esd.2020.12.009

Olubiyi Obada, D., Iheanyichukwu Obi, A., Dauda, M., & Olukayode Anafi, F. (2014). Design and Construction of a Biogas Burner. □□□□ □□□□□ □□□□□□ □□□□□□□ □□□□□□□, *2*(2), 35–42. https://doi.org/10.53671/pturj.v2i2.32

Orhorhoro, E. K., Oyejide, J. O., & Abubakar, S. A. (2018). *Design and Construction of an Improved Biogas Stove*. *14*(3), 325–335. www.azojete.com.ng

Özdemir, M. R., Yangaz, M. U., & Yilmaz, I. T. (2021). Energy, Exergy and Exergo-Economic Characteristics of Hydrogen Enriched Hydrocarbon-Based Fuels in a Premixed Burner. *Energy Sources, Part A: Recovery, Utilization and Environmental Effects*, *43*(23), 3119–3136. https://doi.org/10.1080/15567036.2021.1895371

Petro, L. M., Machunda, R., Tumbo, S., & Kivevele, T. (2020). Theoretical and Experimental Performance Analysis of a Novel Domestic Biogas Burner. *Journal of Energy*, *2020*, 1–9. https://doi.org/10.1155/2020/8813254

Salunkhe, D. B., Rai, R. K., & Borkar, R. P. (2012). *BIOGAS TECHNOLOGY*. *4*(12), 4934.

Santos, S. C., Yamagata, C., & Mello-Castanho, S. (2014). Lighting by Biogas Burners: Perspectives on Development in Brazil. *Materials Sciences and Applications*, *05*(09), 660–673. https://doi.org/10.4236/msa.2014.59068

Schiro, F., Stoppato, A., & Benato, A. (2017). Gas fired boilers: Perspective for near future fuel composition and impact on burner design process. *E3S Web of Conferences*, *22*. https://doi.org/10.1051/e3sconf/20172200154

Singh, G., Verma, S., & Baredar, P. (2019). A Review on Performance of Biogas Stove From Different Design of Burner. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3442426

Sokolov, V. Y., Naumov, S. A., Sadchikov, A. V., & Mitrofanov, S. V. (2017). Use of ceramic injection molding technology to increase biogas burners efficiency. *Key Engineering Materials*, *736 KEM*, 127–131. https://doi.org/10.4028/www.scientific.net/KEM.736.127

Sun, M., Huang, X., Zhao, Y., Zhang, P., & Zhou, Y. (2021). Design of a partially premixed burner for biogas-fired wall-mounted boiler. *International Journal of Low-Carbon Technologies*, *16*(1), 212–219. https://doi.org/10.1093/ijlct/ctaa055

Suslov, D. Y., Ramazanov, R. S., & Shvydkaya, M. A. (2018). To the Question of Biogas Combustion in Vortex Burners. *Journal of Physics: Conference Series*, *1066*(1). https://doi.org/10.1088/1742-6596/1066/1/012028

Suslov, D. Y., Ramazanov, R. S., Temnikov, D. O., & Lobanov, I. V. (2019). Development and research of low pressure injection burner for biogas combustion. *IOP Conference Series: Materials Science and Engineering*, *552*(1). https://doi.org/10.1088/1757-899X/552/1/012031

Tariku, A. (2020). *DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF AN IMPROVED BIOGAS INJERA BAKING STOVE DEPARTMENT OF MECHANICAL ENGINEERING (THERMAL STREAM) COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING*.

Tucho, G. T., & Nonhebel, S. (2015). Bio-wastes as an alternative household cooking energy source in Ethiopia. *Energies*, *8*(9), 9565–9583. https://doi.org/10.3390/en8099565

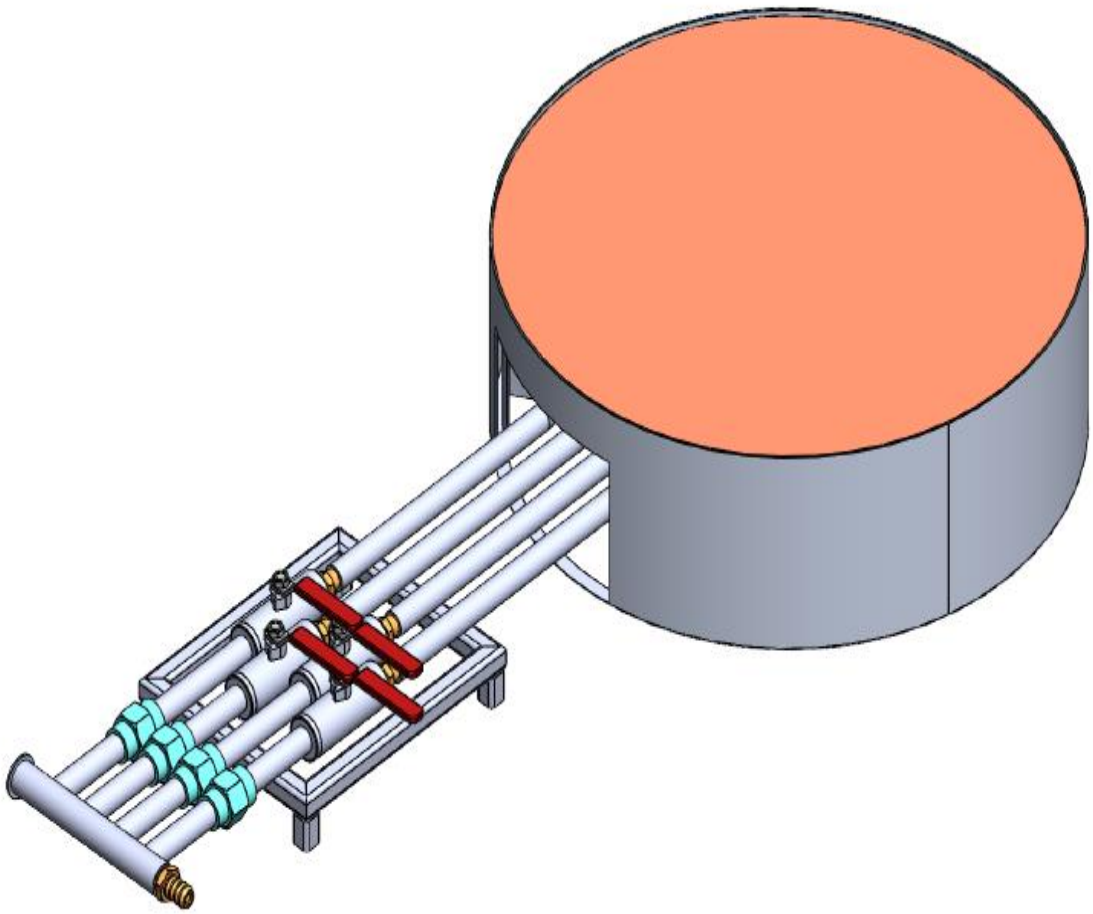
Yatim, A., Luthfi, A., & Chemilo, R. (2018). Biogas-fuelled Stirling engine for electric power generation. *E3S Web of Conferences*, *67*, 1–6. https://doi.org/10.1051/e3sconf/20186702015

Yirgu, B. M., Tekestebrihan, D., Demissie, S. W., Mulugeta, B., Demissie, S. W., & Nega, D. T. (2017). Design, Optimization and CFD Simulation of Improved Biogas Burner for "Injera" Baking in Ethiopia. In *Article in International Journal of Engineering Research*. www.ijert.org

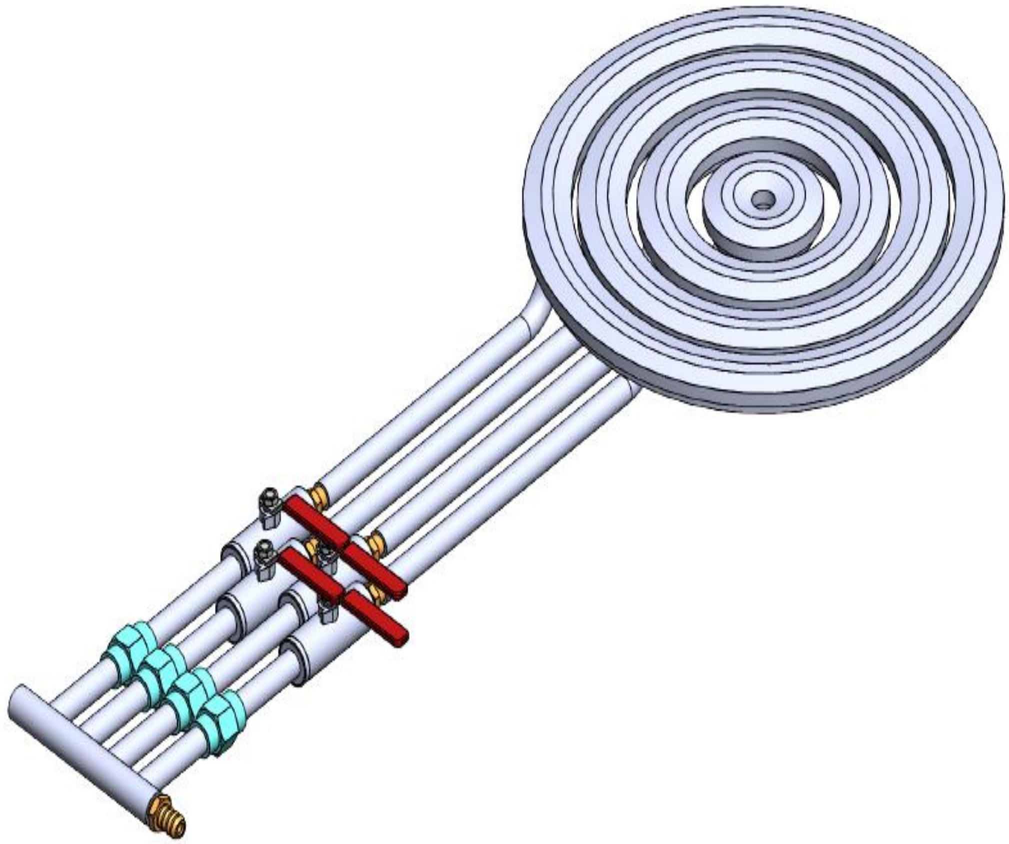
Zigale. (2020). *DSpace Institution DSpace Repository http://dspace.org Energy Center Thesis and Dissertations PERFORMANCE EVALUATION OF THREE BIOGAS COOKING STOVES FOR INJERA BAKING*. http://hdl.handle.net/123456789/10601

APPENDICES

Appendix 1: Assembly drawing of newly developed an improved Aluminum biogas injera baking Stove. It consists of burner head, baking pan, Channel, and mixing tube

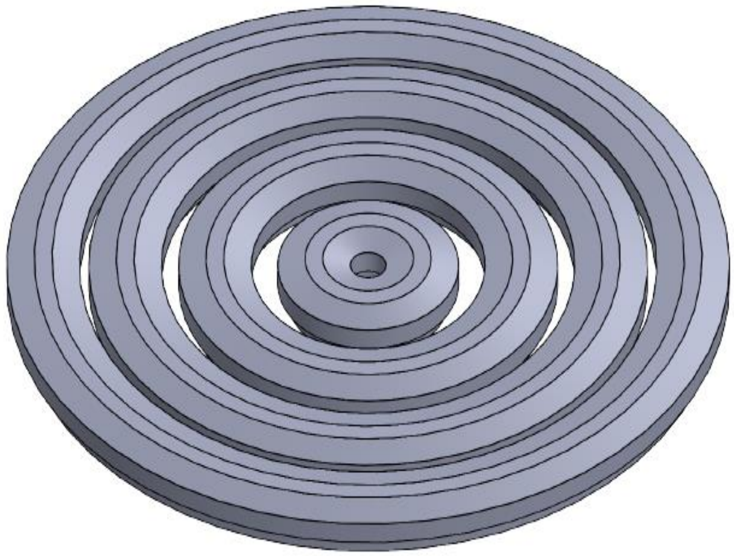


Appendix 2: burner with its integrated parts without baking pan.

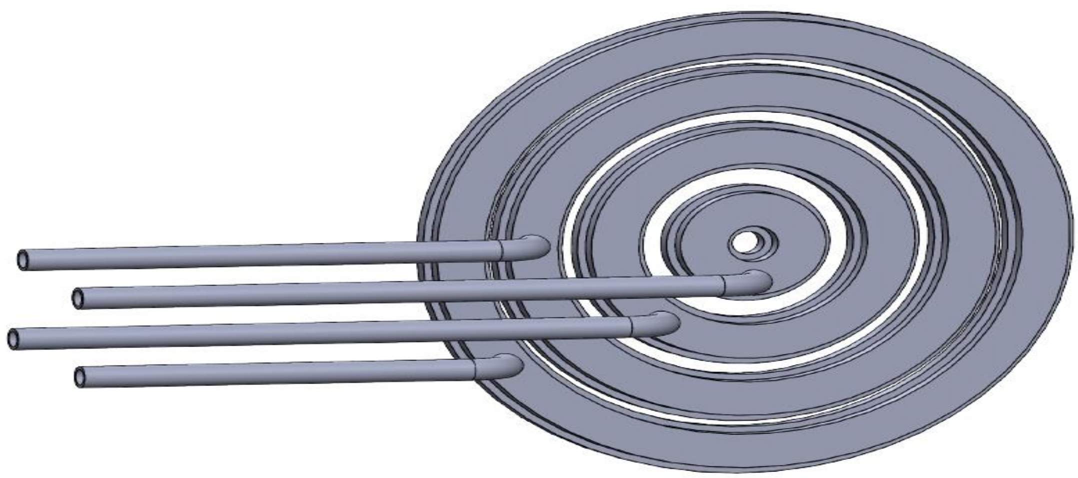


Appendix 3: 3D drawing of part component of newly developed biogas injera baking stove

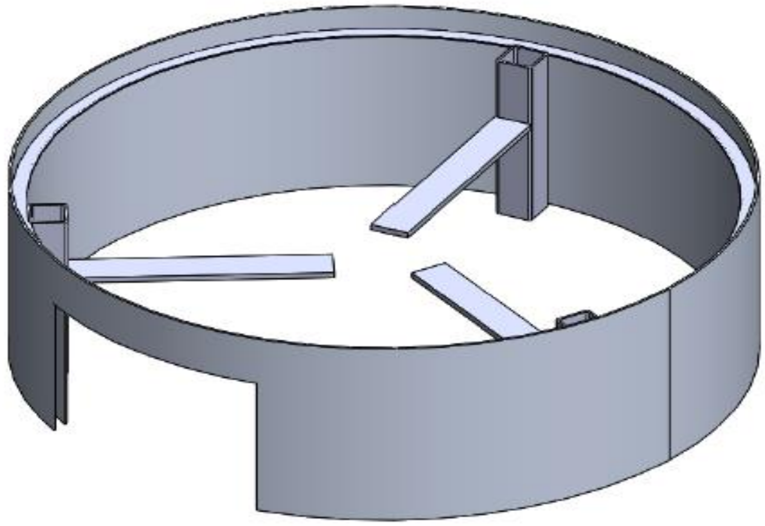
B. Burner Head



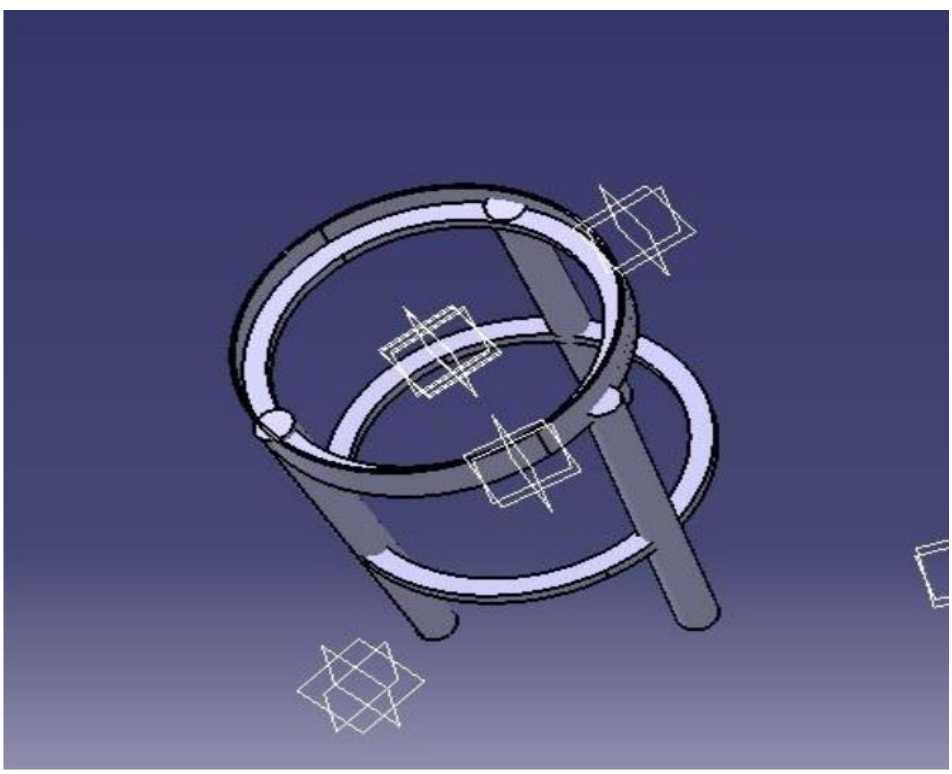
C. **Burner Head with Channel**

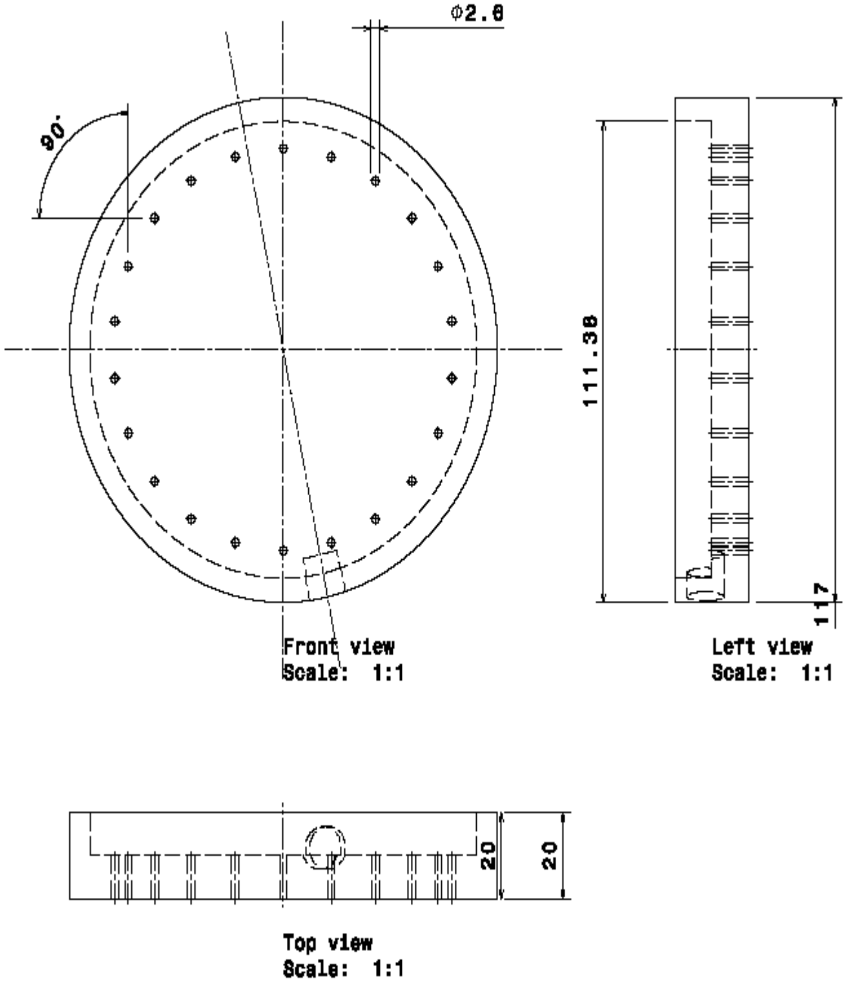


D. **Combustion Chamber**

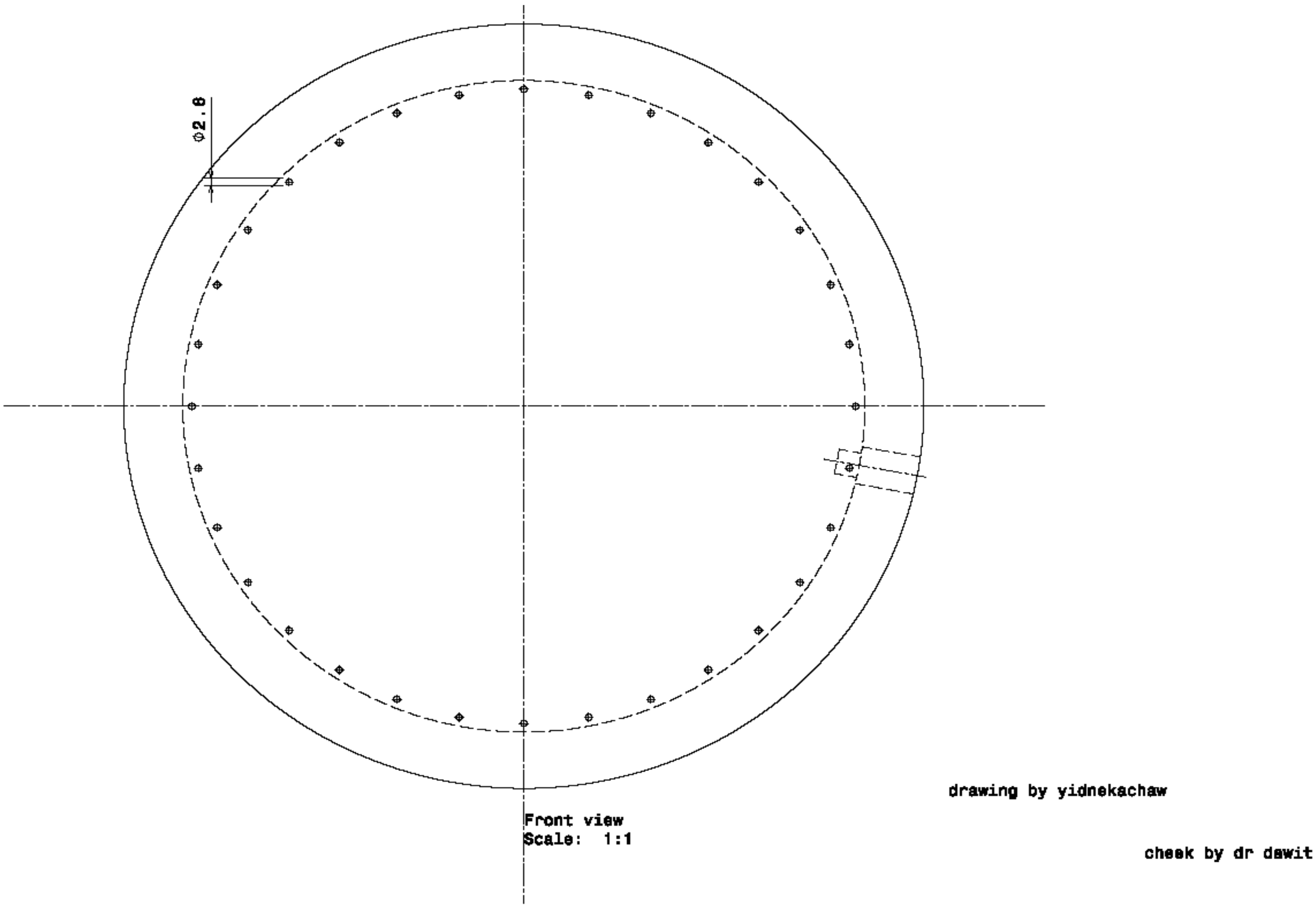


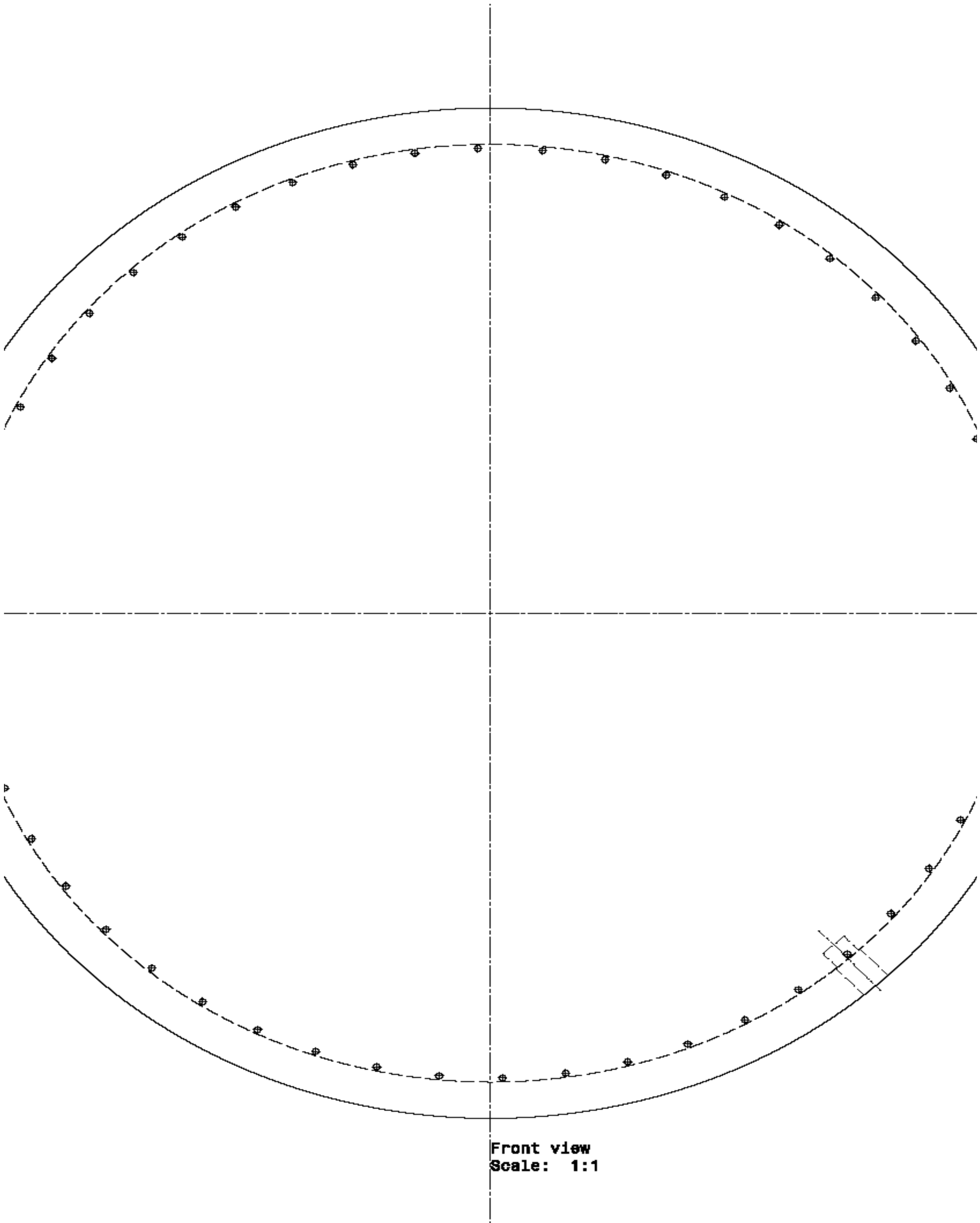
E. **Leg**

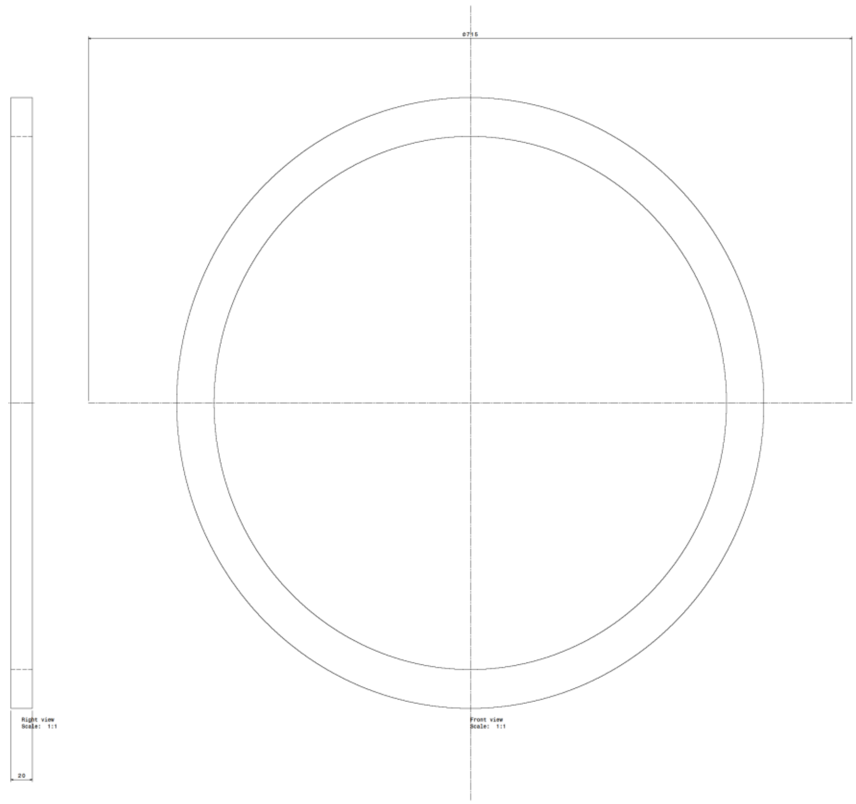


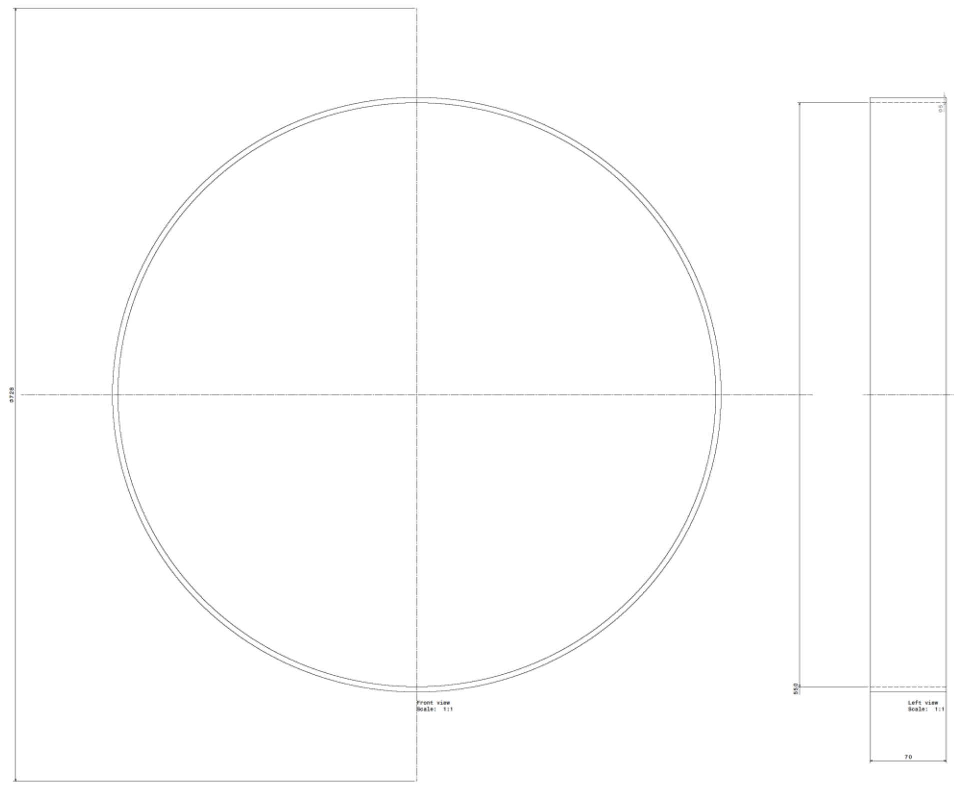


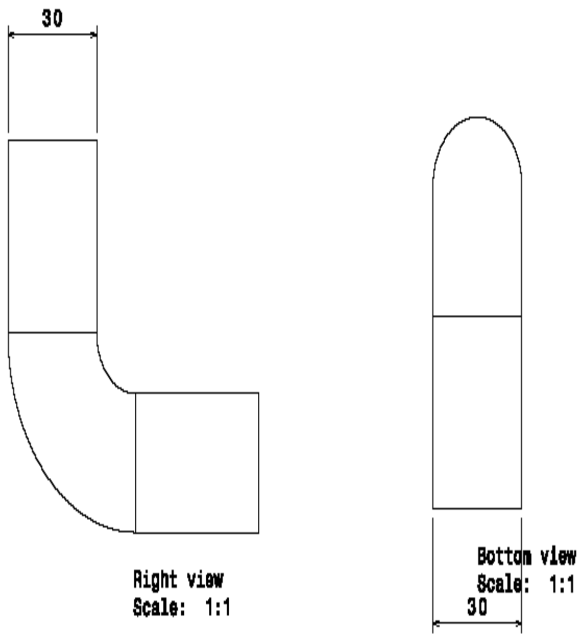
drawing by Yidnkachew Dirsha
Checked by Dr. Dawit Gudeta


Φ2.8
Front view
Scale: 1:1
drawing by yidnekachaw
cheek by dr dawit


Front view
Scale: 1:1


Ø715
Right view
Scale: 1:1
20
Front view
Scale: 1:1


Ø728
Front view
Scale: 1:1
550
Left view
Scale: 1:1
70


30
Right view
Scale: 1:1
Bottom view
Scale: 1:1
30