ADDIS ABABA SCIENCE AND TECHNOLOGY UNIVERSITY

DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF AN IMPROVED BIOGAS INJERA BAKING STOVE

A MASTER'S THESIS

BY

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DEPARTMENT OF MECHANICAL ENGINEERING (THERMAL STREAM)

COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

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A Thesis Submitted as a Partial Fulfillment to the Requirements for the Award of the

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APPROVAL

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This is to certify that the thesis prepared by **Atsede Tariku** entitled **"Design, Development and Performance Evaluation of an Improved Biogas Injera Baking Stove"** and submitted as a partial fulfillment for the award of the Degree of Master of Science in Mechanical Engineering (Thermal Engineering) complies with the regulations of the university and meets the accepted standards with respect to originality, content and quality.

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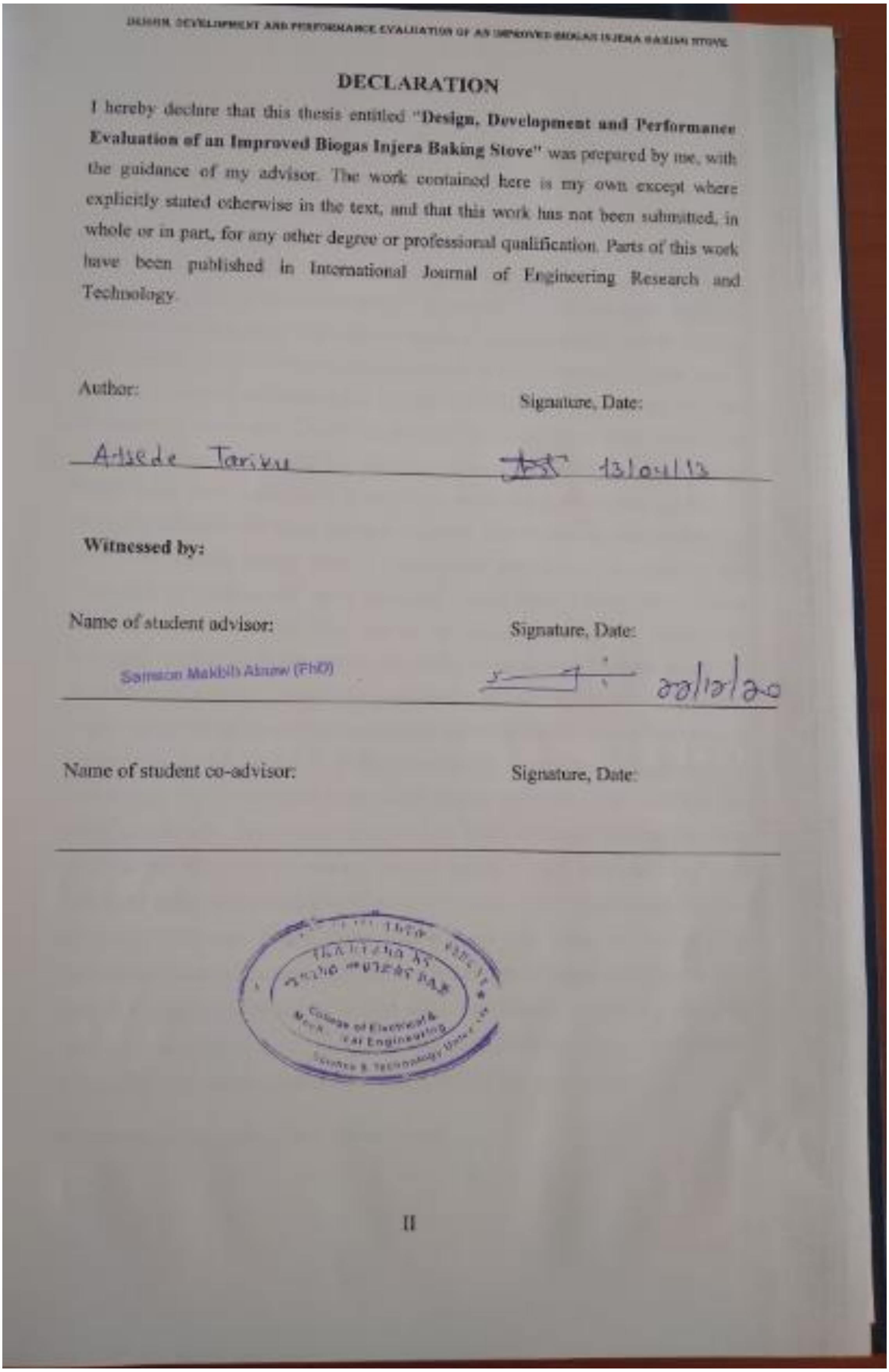
DESIGN, DEVELOPMENT AND PERFORMANCE EVALUATION OF AN IMPROVED BIOGAS INJERA BAKING STOVE

DECLARATION

I hereby declare that this thesis entitled "**Design, Development and Performance Evaluation of an Improved Biogas Injera Baking Stove**" was prepared by me, with the guidance of my advisor. The work contained here is my own except where explicitly stated otherwise in the text, and that this work has not been submitted, in whole or in part, for any other degree or professional qualification. Parts of this work have been published in International Journal of Engineering Research and Technology.

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II

ABSTRACT

Injera is Ethiopian and Eritrean favorite food. In Ethiopia till now approximately 70-80% of the primary energy for cooking is taken from biomass. Gathering wood for fuel and burning in inefficient stoves leads to local scarcity and ecological damages. Such extensive use of biomass in traditional and inefficient ways caused drought, environmental pollution, GHG emission and health problems. To avoid or minimize these problems promotion to alternative renewable energy source, which is energy efficient and cost efficient like biogas technology is receiving much attention. Nowadays in Ethiopia the implemented biogas is providing energy only for lighting and cooking. However, previously implemented biogas injera baking stoves have a problem of uniform heat distribution through the baking pan, heat loss and high fuel consumption. In this study, Analytical design of the biogas stove, development of an improved biogas injera baking stove and experimentally testing of the performance of biogas based injera baking stove is carried out. Additionally, the economic projection of biogas utilization for injera baking is evaluated. The experiment was conducted in controlled cooking testing method. Experimental performance investigation was conducted in existing and newly developed biogas injera baking stove. During experimental test cooking time, amount of biogas consumption, temperature, efficiency, amount of energy needed and quality of injera were the main parameters considered in order to evaluate the performance of existing and newly developed biogas injera baking stove. The experimental test result showed on the first round of baking process the amount of biogas consumption for baking a single injera by existing and newly developed biogas injera baking stove was 9.26 litters and 1.45 litters respectively. The cooking time for 9.26 litters of biogas consumption takes 19.033minute. However the cooking time for baking a single injera by using newly developed biogas injera baking stove was 1.45 minute. From experimental test result the newly developed biogas injera baking stove was found to have a better performance than the existing one. The newly developed biogas injera baking stove showed a remarkable reduction in time taken and amount of biogas consumption compared with existing stove. This study also showed attractive economic feasibility with positive net present value and payback period of less than one year.

Keywords: Injera, cooking time, Stove, Biogas

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NOMENCLATURES

ABBREVIATIONS

BTC	Burayou Basic Technology Center
CCT	Controlled Cooking Test
CHS	Circular Hollow Steel
FEM	Finite Element Method
GHGs	Green House Gas
GIZ	German Agency for International Cooperation
GTZ	German Agency for Technical Cooperation
NPV	Net Present Value
RHS	Rectangular Hollow Steel
WBT	Water Boiling Test

LIST OF SYMBOLS

A	The circumferential area of the cylinder
A_p	Total burner port area
A_j	Area of orifice
A_t	Area of throat
B	volumetric coefficient of expansion of air
Cal	calorific value
$C_{p,p}$	Specific heat of pan
$C_{P,dough}$	Specific heat of dough
C_r	Cooking rate
d_j	Diameter of orifice (jet)
d_t	Diameter of throat
d_p	Diameter of flame port
D_f	Diameter of flam port
g	Acceleration due to gravity
h_{lc}	Heat transfer coefficient b/n baking pan and lid cover
$h_{c,o}$	Outer convectional heat transfer coefficient
$h_{c,i}$	Internal convectional heat transfer coefficient
h_{1r}	Radiative heat transfer coefficient from the baking pan to lid cover

H_f	Flame height
K	Thermal conductivity
L_m	Length of mixing chamber
L_n	The space between the flame and plate
L_{pl}	Length of pan to lid covers
$m_{,dough}$	Mass of dough
m_p	Mass of baking pan
ΔP	Pressure drop
P	Gas pressure before orifice (mbar)
P_t	Pressure of gas is in throat
P_O	Atmospheric pressure
p_{out}	Desired output power
$p_{required}$	Required input power
$\dot{Q}$	Heat flow across the face
Q_{biogas}	Biogas flow rate
Q_m	Flow rate of mixture in the throat
r_1	Internal radius
r_2	Outer radius
R	Discount rate
T_1	Ambient temperature
T_2	Baking temperature
T_i	Initial Temperature
ΔT	Mean temperature
T_{lc}	Temperature of lid cover
T_p	Temperature of baking pan
T_b	Baking time
T_a	Ambient temperature
T_b	Baking Temperature
T_f	Final Temperature
U	Overall heat transfer coefficient
U_t	Total effective top heat transfer coefficient from baking pan surface to the ambient
V_j	Velocity of gas in the injector orifice

V_t	Velocity of gas in a throat
V	Volume of gas
V_P	Mixing supply velocity
Y	Number of years

DIMENSIONLESS GROUPS

C_d	Coefficient of discharge for the orifice
f	Flame speed factor
G_r	Grashoffs number
N_u	Nusselt number
n_p	Number of ports
P_r	Pradlt number
r	Entertainment ratio
R_a	Rayleigh number
R_e	Reynold number
S	Specific gravity of gas
ε_{eff}	Effective emissivity of the baking pan

GREEK LETTERS

ζ	Stefan Boltzmann constant
γ	Kinematic viscosity
μ	Viscosity of mixture
ρ	Density of gas
ρ_m	Density of mixture
η	Efficiency of baking stove

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Chapter One

1. Introduction

1.1 Background of the Study

Injera is the staple flatbread food item in Ethiopia. When one thinks of cooking in Ethiopia, one thinks immediately of Injera bread, in which its preparation usually takes two to three days and in most of the cases the crop Teff is used for injera. Gathering, preparing, and consuming food is subject to many cultural considerations. It is known that, the energy requirements in developing countries are largely met from biomass, and the options for cooking food is limited, Most of the time they rely on wood as a primary fuel and cooking on simple open fires. In Ethiopia gathering wood for fuel and burning in inefficient stoves leads to local scarcity and ecological damage in areas of high population density where there is strong demand of wood for domestic purpose. The annual per capita consumption of biomass fuels for domestic purpose in rural areas is estimated in the range of 0.7 to 1.0 ton; the share of woody biomass from the total is about 80%, the rest comes from crop residue and animal dung [1].

Figuer1. 1 Injera baked by biomass fuel

Figure 1.1 shows injera baked by biomass fuel. As shown from the above figure the texture or the structure of injera baked by biomass fuel is poor at the top face. The extensive use of biomass in traditional and inefficient ways causes GHG emission, health problems, and environmental pollution and restrains economic and social development. To avoid or minimize these problems and increased concerns over the local, regional and global environmental impacts of conventional energy systems;

promotion to alternative renewable energy sources which are energy effective and cost efficient like biogas technology are receiving much attention. Thus designing and manufacturing of biogas stove used for injera baking have important role to solve the problem.

Technical advances in energy efficiencies are critical for developing countries like Ethiopia, whose populations depend primarily on biomass fuels such as wood, charcoal and agricultural residues. Overuse of these fuels deplete resources, degrade local environments, spent time needed to collect fuel, and creates indoor air pollution that cause health problems.

Figuer1. 2 Traditional 3 stone biomass injera baking stove

Figure 1.2 shows traditional three stone biomass injera baking stove. As shown from the above figure the tradition stove is subjected to excessive heat loss and higher biomass fuel consumed. In Ethiopia the primary source of energy is biomass, which accounts for 91% of energy consumed [2]. Petroleum supplies about 7% of total primary energy and electricity ack2counts for only 2% of total energy use. Biomass consumption accounts for over 98% of total supply in the residential sector. The World Development Indicators[3] and many other studies [4-6] show that the national energy balance is dominated by a heavy reliance on firewood, crop residues, and dung. Due to the dependence on biomass for cooking, CO_2 emissions in Ethiopia have increased from 5.1 million tons in 2005 to 6.5 million tons in 2010. On a per capita basis, this amounts to 0.06 tons of CO_2 in 2005, 0.075 tons in 2010, and 0.19 tons in 2014

. Because injera is such a large part of our diet, alternative and more energy efficient cooking methods need to be taken into account. One alternative is to use fossil fuels like kerosene, or liquefied petroleum gas; but these are expensive and having a higher pollution level. So to reduce and thus to avoid the addressed problems, it is important to address the escalating need for a new fuel source by utilizing renewable energy like solar energy, wind energy, hydro energy and biogas. But, biogas is distinct from other renewable energies because of its characteristics of operation, controlling and collecting organic wastes and at the same time producing fertilizer and water for use in agricultural irrigation. Biogas does not have any geographical limitations nor does it require advanced technology for producing energy, also it is very simple to use and apply. Biogas is one of the promising clean energy for households[7].

Biogas is a modern form of bioenergy that can be produced through anaerobic digestion or fermentation of a variety of biomass sources. These include, but are not limited to, livestock manure, food waste, agricultural residues, energy crops, sewage and organic waste from landfills. It is a versatile fuel that can be used for cooking, heating, lighting, power generation, and combined heat and power generation, as well as, when upgraded to boost its methane content, in transport applications. Biogas typically consists of 50–75% methane, which provides its energy content, and 25–50% carbon dioxide[8].

Biogas stove is a relatively simple appliance for direct combustion of biogas. Its burner is a premix and multi-holed burning ports type and operates at atmospheric low pressure. A typical biogas stove consists of gas supply tube, gas tap/valve, gas injector jet, primary air opening(s) or regulator, throat, gas mixing tube/manifold, burner head, burner ports (orifices), pot supports and body frame. So it is important to use the technology of using biogas for injera baking system in order to reduce the problems caused by the use of traditional biomass cook stoves. The efficiency of using biogas is 55% in stoves, 24% in engines and 3% in lamps[9].

Nowadays a number of researchers were intended to design and developed a biogas injera baking stove. But previously implemented biogas injera baking stoves have a problem of poor heat distribution through the baking pan and resulting higher fuel consumption. The present research aims at developing a biogas cook stove for injera baking purpose that will enhance uniform heat distribution on the surface of baking Mitad by utilizing tubular type burners; using better constructing materials; by modeling an alternative geometries and also selecting the best one among them; by improved geometry; Experimentally tested the performance of the stove by considering uniform temperature distribution, cooking time, quality of injera and amount of biogas consumption finally comparison of efficiencies of the newly developed stove with the existing biogas injera baking stove.

1.2 Problem statement

Now a day in remote (rural) area of Ethiopia, 75% of energy is extracted from wood. Using firewood causes a number of environmental and health problems. To avoid or minimize these problems and in order to address the increased concerns over the local, regional and global environmental impacts of conventional energy systems; promotion to alternative renewable energy sources which are energy effective and cost effective such as biogas technology are receiving much attention. In Ethiopia, the implemented biogas gives advantageous only for lighting and cooking purposes. However, previously implemented biogas stove used for Injera baking application have the problem of poor heat transfer through the stove, heat loss and high fuel consumption. This is due to unequal distribution of heat throughout the baking pan. In addition, as a result, of small burner diameter the heat distribution through baking pan is not uniform. This causes unequal distribution of heat on injera baking Mitad.

1.3 Research Questions

Q1. What design mechanisms can be developed to obtain uniform heat distribution through injera baking pan of biogas cook stove?

Q2**.** How can introduce or improve the existing injera baking biogas cook stove with modification, low cost and more efficient from local market available materials?

1.4 Hypothesis

This research work intends to develop biogas cook stove design for injera baking application that is intended to bake an injera with uniform heat distribution on a baking pan as well as replace the higher firewood consumption of households that could be used for cooking by biogas. In addition, this study aims to reduce the biogas consumption and baking time required.

1.5 Objectives

1.5.1 General objective

The main aim of this research work is to Design, Develop and carryout experimental performance investigation of an improved biogas cook stove for injera baking application.

1.5.2 Specific objective

The specific objectives of this research work are:

- Analytical design of improved biogas based injera baking stove

- Fabricate the biogas injera baking stove
- Experimentally investigate the performance of newly developed biogas based injera baking stove and compare its efficiency and cooking time with existing stoves.
- Evaluate the economic analysis of biogas utilization for injera baking

1.6 Scope of the present work

In this research work the Design, Development and Performance evaluation of an Improved Biogas Cook Stove for Injera Baking was done. The study would try to throw some insights into the shortcoming of existing biogas injera baking stove designs in terms of uneven heat distribution and lower energy efficiency. The actual performance of new cook stove, efficiency and baking time capacity was analyzed and tested. The sequence of this work is described as follows:

Activity one: First of all selecting 8m^3 biogas digester to evaluate the burner performance.

Activity Two: Obtain information on the maximum gas pressure obtainable in the digester selected. The maximum operational pressure of biogas on a digester was 8kp. This information was obtained from keyet woreda house hold view.

Activity Three: In order to determine the parts sizes of biogas injera baking stove by Analytical method.

Activity Four: Selecting the materials for the 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 existing and newly developed biogas injera baking stoves was done.

1.7 Significance and application of the study

The benefits associated with stove technology improvement fall in two categories: those that are internal to the household and those that are external.

Internal benefits include

- Reduced concentrations of smoke and indoor air pollution;
- `Saved money and time in acquiring fuel; and
- Reduced biomass use, ability to use animal dung as fertilizer instead of as fuel.

External benefits include

- Reduce deforestation;
- Reduced GHG; and
- Skill development and job creation to the community.

Chapter Two

2. Literature Review

A number of researchers intended to design and develop an injera baking stove for the community. Especially in Ethiopia different types of injera baking stove technologies were developed from early to recent period. Now in this section, early and recent research efforts on improvement of injera baking stove is discussed.

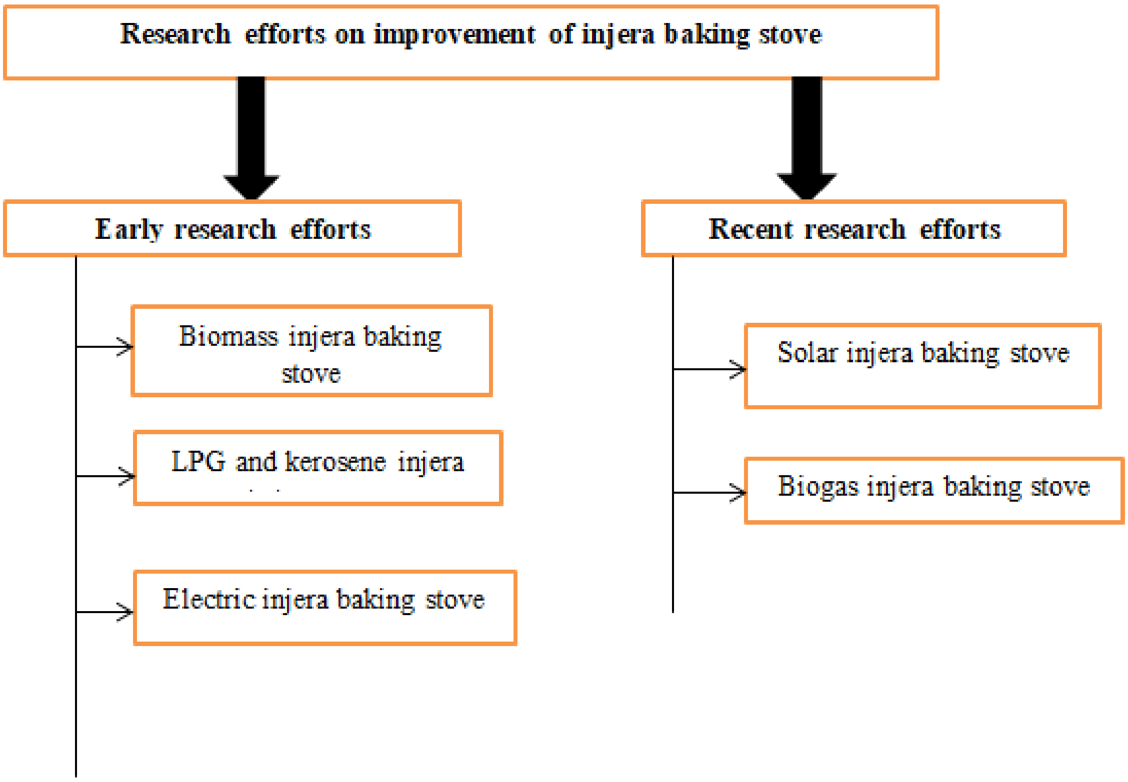


Figure2. 1 Research efforts on improvement of injera baking stove

Figure 2.1.shows the overall research efforts on improvement of injera baking stove. As shown in the Figure above Ethiopian research efforts for improvement of injera baking stove could be classified and discussed in to two ways such as early efforts on improvement of injera baking stove and recent efforts on improvement of injera baking stove. Early research improvement effort could be classified and discussed based on energy (fuel usage) such as biomass, kerosene as well as LPG and electric injera baking stoves. On the other hand recent efforts on improvement of injera baking stove could be discussed in the following ways such as solar, electric and biogas injera baking stove

2.1 Early research and development efforts for improvements of injera baking stoves

2.1.1 Biomass injera baking stoves

The efficient need for injera baking stoves had not been addressed for a long period of time until governmental institutions laid the foundation in the 1980s. The Early efforts included by manufacturing of mud injera baking stoves by the Burayou Basic Technology Center (BTC), under the Ministry of Education in the early 1980s. The name of the stove was ‘Burayou mud-stove’. Then Ethiopian Science and Technology Commission (now Ministry of innovate and Technology of Ethiopia) hired a consultant in 1981 to assess traditional closed stove in selected areas of the country [10].

In 1986, the Ambo team modified the Burayou mud-stove and came up with the Ambo mud-stove used for injera baking [11].

In the early 1990s, a team of experts at 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 [12]. 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 [13]. 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% [14]. Compared to the three stone open fire injera baking stove, it consumes less fuel, and is easier to use and protects from burns. The thermal efficiency of traditional three stone biomass stove is around 5-9% [15].

Tehesh injera baking stove was developed by GIZ (previously GTZ) and the Rural Technology Promotion Center of Mekele. The idea of designing Tehesh came from improving the existing Tigrian injera baking stove.

The raw materials needed for the making of Tehesh are mud, stones, and straw. Small amount of fresh dung is mixed together with mud to increase its adhesion. This mixture is smeared over the vertically stacked stone from inside and outside. The straw is used as insulation by placing it between the outer and inner walls of the stove and under the combustion chamber[16].

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 baking 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. 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 [17].

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’ [12].

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 [18]. Mirt stove was tested at the Aprovecho Research Center; the test was conducted using the water boiling test procedure where the time to boil is 35.8 min and 6407 g of fuel was used. The CO observed was 192 g and PM was 5322 g. The improved design brought about a percentage reduction of 18% (time to boil), 81% (fuel use), 90% (CO), and 83% (PM) [18].

The other improved injera baking stove is made out of clay and its name is Gonziye. It is a multipurpose improved cooking stove to be used both for injera baking and other types of cooking such as water heating, coffee making and (wot) preparation.

The specific fuel consumption of Gonziye injera baking stove is 617 g/kg of injera [19].

Awramba is the other improved injera baking stove which is named after the Awramba community in Amhara Regional State. This injera baking stove has been in use in the community since 1971. This stove also integrates other cooking applications in addition to injera baking. It has a specific fuel consumption reduction of 35% compared to the open-fire injera baking stove.

Table2. 1 Biomass injera baking stoves

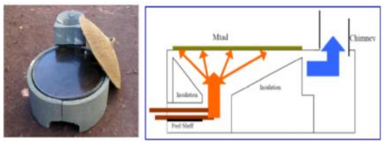
No.	Improved biomass injera baking stoves	
1.		3- Stone Biomass injera baking stove
2.		Tehesh biomass injera baking stove
3.		Mirt biomass injera baking stove
4.		Gonziye biomass injera baking stove
5.		Awramba biomass injera baking stove

Table2. 2 Types of improved house hold injera baking stove

1. Addis/Aprovecho Stove	 Addis or Aprovecho Stove	stove made of cement, a combination of mirt and rocket stove, no expansion chamber, no potrests but air inlet, developed by Aprovecho in 2006 on demand of GTZ
2.Yekum Injera Mitad	 Yekum Injera Mitad	Brick stove cladded with metal, with chimney and on 4 legs, can be found in major cities, price from 600 – 1.200 Birr, sometimes called “Laketch”. .
3.Yekum Mirt – II	 Yekum Mirt II	Mirt stove of which is made of cement, cladded with metal, no potrest, no expansion chamber, one chimney, height was reduced from 24cm to 18, can be found around in Adama in Oromia Region in few numbers, stove was adapted by a trained stove producer,

2.1.2 LPG and kerosene injera baking stoves

The number of LPG users in Ethiopia is relatively low for decades due to the high prices of the gas and its appliances. LPG stove was also tested for injera baking appliance. During the test, a gas burner imported from Krampous, in France, with clay plate of 50 cm diameter was used. The Krampous burner was designed for the preparation of “crepes” (pancakes). For injera baking purpose, the cast iron baking plate was replaced by a clay plate. The specific energy consumption with LPG was much higher than wood and electricity which might have been caused by the high power of the gas stove with about 6 kW[20].

2.1.3 Electric injera baking stoves

Electric injera baking stove (electric injera Mitad) was introduced to Ethiopia 40 years [21] back through the then Ethiopian Electric Light & Power Authority (EELPA). In order to disseminate the electric injera stove, various government and private organizations produced the stove and sold it to the market. Since the electric injera baking stove is not standardized, the performance of the electric injera baking stove depends on the experience of the company and the quality of the workmanship. The average power demand of a single household electric injera baking stove is in the range of 3 to 4 kW. The Ethiopian Energy Authority is in the process of preparing the Ethiopian standard for labeling electric injera baking stoves in order to create awareness for the users to select their preference according to their interest based on the performance of the stove [22].

2.2 Recent research effort on improvement of injera baking stoves

Recent researches efforts on improving the performance of injera baking stoves have increased due to environmental and health concerns. According to the study of [23] the maximum reduction of specific fuel consumption of improved injera baking stoves related to traditional three stone open fire stove in Ethiopia is 49% while the minimum is 34% .similarly the maximum % reduction in in CO during the test period was 91% while that of PM was 19.3% in comparison with an open fire injera baking stove [23].

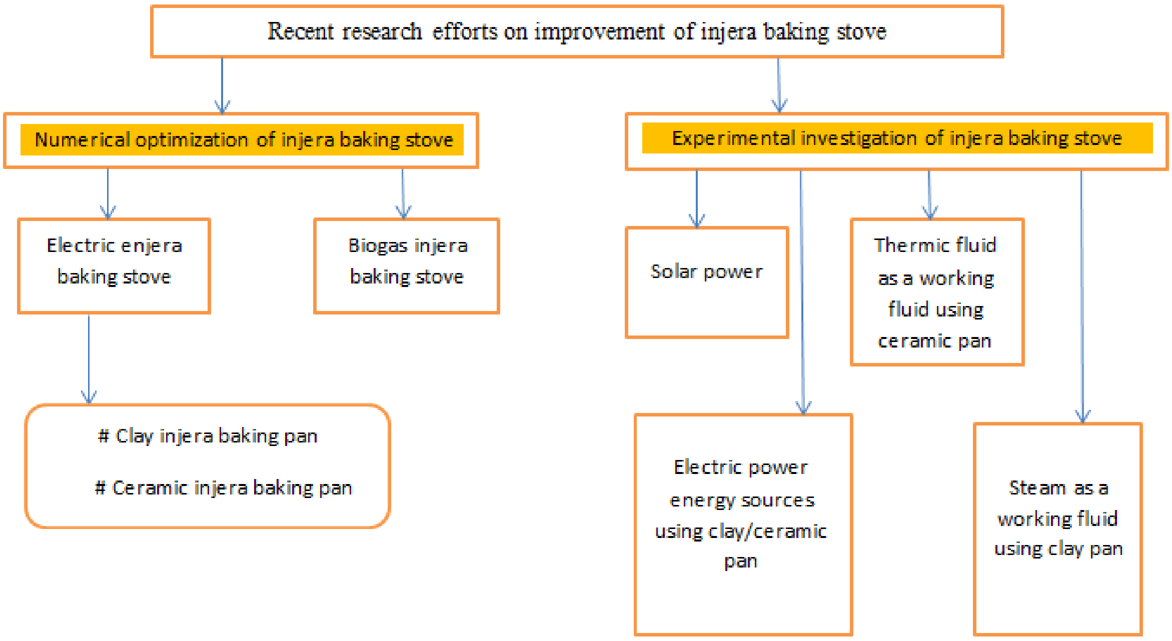


Figure2. 2 Recent research efforts on improvement of injera baking stoves

Figure2.2 shows recent research efforts on improvement of injera baking stove. As shown in figure above recent research efforts could be disused in two ways first numerical optimization of an injera baking stove and Experimental investigation of injera bake stove. Electric injera bake stove and solar injera bake stove were numerically optimize and experimentally investigated by a number of researchers. On the other hand biogas injera baking stove was studied by some researchers and also the study was discussed by numerical optimization method, FEM and also by using CFD software. Electric power injera baking stove using clay /ceramic pan also studied by various researchers. Solar power injera baking stove was discussed based on working fluid such as thermic fluid as a working fluid using ceramic pan and steam as a working fluid using clay pan.

2.2.1 Electric heat transfer fluid injera bake stove

Urban areas widely use electric injera bake stove that where the grid electricity were available. A number of researches conducted numerically and experimentally investigate electric injera bake stove. The bake Mitad was originally made up of clay and ceramic pan. The average thermal efficiency is 50% for clay and 60% for ceramic plate.

2.2.1.1 Electric injera bake stove research output

Most of the study[24-26], conducted numerically and experimentally investigate electric injera bake stove. Assefa et al.[24] Conducted the heat transfer analyses of injera bake pan by FEM. The major research output of this study was as follow: The FEM is used to model heat transfer process during injera bake using glass plate. This was experimentally verified using electric injera bake stove. The major improvement was predicted if the cooking plate thickness is minimized or thermal conductivity increased. Gashaw et al.[25] Developed mathematical model of finite element formulation for baking pan and injera during baking and also the simulation was done in terms of temperature profile during heat up and cyclic injera bake using mat lab. The simulation was performed for four different electric power source (1.867 kw,2.2 kw , 2.5 kw and 3 kw) using two types of bake pans (clay and ceramic), and also the efficiency was achieved for bake cycle of 10-56 injera is 53-66% for clay pan and 66-72% for ceramic pan. Awash et al.[26] Experimentally investigate the performance characteristics and efficiency of electric injera bake pans. In this study the maximum energy losses occurred at the bottom of conventional and improved (ceramic) bake pans with the efficiency of 52% and 75%, respectively.

Table2. 3 Electric injera baking Mitad structure and stove

Electric injera baking stove part		
Back side before sealing,	Backside sealed with gypsum	Assembled electric injera baking stove
		

2.2.2 Solar powered injera bake stove

A number of researchers were tried to study injera bake stove operated by solar energy (power). The major output of the studies obtained by experimental investigate are mainly use of steam as a working fluid for injera baking with a temperature range of 135-160^{o}c and on the other hand to bake an injera using direct solar radiation reflector on a cooking pan at 180^{o}c. the studies showed numerically investigation of injera bake with solar injera clearly showed a promising result. The experiment was conducted based on a simulated electric heater to heat the thermic fluid circularly in the bake process.

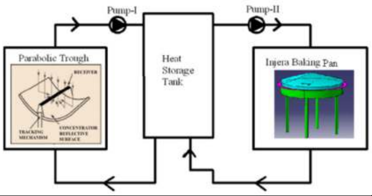
Most of the studies [27-32], reported the result of solar thermal injera baking stove. Mekonnen et al. [27] Design and Manufacture the laboratory model solar powered injera bake oven. In this study injera baking oven system consist of oil storage and heat tank, pumping and piping system, baking pan assembly and support structure. The system uses electrical heater to heat the thermic fluid to be used for baking. Finally the result shows the temperature of 215^{o}c is achieved on baking pan and baked injera. Asfafaw et al.[28] Design and Developed solar thermal injera baking with the working fluid of steam based direct baking. They introduced indirect solar stove. A parabolic dish with an aperture area of 2.54m^2 with well insulated pipe and stainless steel heat exchanger to bake injera. The experimental test result showed that the high temperature indirect steam baking of injera is possible. "The authors claim that injera could be baked at a temperature of 135-160^{o}c within acceptable quality." Abdulkadir et al.[29] Experimentally investigate the performance of solar powered injera baking oven for indoor cooking. The solar thermal energy was transferred to the kitchen by means of a circulating heat transfer fluid which is heated by parabolic trough. The baking pan made from ceramic is manufactured and used for injera baking application. In order to heat the ceramic baking pan a steel pan with fins is put underneath and the oil enters the cavity to transfer the heat to the fins and steel. It takes 1hr to start circularly the oil is 40 min to reach the optimum baking temperature (180^{o}c -220^{o}c). 5 injera was baked at an interval of 2 min and idle time of 3min between each injera.

Abdulkadir et al.[30] Conducted finite element model of solar powered injera baking oven for indoor cooking. A 2D transient Finite Element Analysis was carried out for a new type of solar powered injera baking system.

In this study the heat transfer oil is heated using solar energy by parabolic trough and the oil circulates through the space below the baking pan in the kitchen. Based on the previous finite element study on the exist electric injera baking pan, a new type of baking pan made from ceramic with 8mm thickness was manufactured and used for the proposed system. The given baking pan that uses solar energy gives an acceptable baking time and heat up compared to the existing conventional baking method.

The FEM predicts well the temperature distribution during initial heat up and cyclic baking.

Table2. 4 Types of improved solar power injera baking stove

Solar powered injera baking stoves		Reference
1. 	Parabolic dish solar thermal injera baking stove (sketch & actual test-rig)	Asfafaw et al.[28]
2. 	Prototype of injera baking frying pan	Gallagher et al.[33]
3. 	Injera baking using solar power with thermic-fluid as a working fluid	Abdulkadir et al.[29]
4. 	Solar powered heat storage for injera baking	Asfafaw et al.[34]

2.2.3 Biogas injera baking stove

Several research works were conducted in biogas stove technology. Biogas stoves can deliver numerous benefits over traditional cooking practices such as mitigation of fecal-borne and parasitic diseases through the removal of openly defecated dung; reduction in household air pollution; fuel substitution for firewood, reducing fuel collection time and easing strain on local forests; combustion of methane reducing methane emissions, eliminating this greenhouse gas that has a global warming potential over 20 times greater than CO2; generation of fertilizer (biogas slurry) that is more potent and of higher quality than conventional fertilizer, which can lead to increased yields[1, 35-40]. A cost-benefit analysis of biogas plants in Ethiopia recently confirmed positive net benefits to households [41].

As combustion of wood and dung generally is incomplete, toxic gases and small particles are emitted besides the fact that they have low energy efficiency. According to WHO, health risks caused by indoor air pollution is one of the most threatening evitable risk factors in developing countries [42]. Various efforts were made to reduce indoor smoke and the fuel wood consumption with the help of improved stoves and alternative cooking methods. Due to wood shortage and the opportunity costs of dung as fertilizer, alternative renewable energy sources which are energy effective and cost efficient like biogas technology are receiving much attention.

Biogas, an alternative fuel that is both sustainable and renewable which is produced from anaerobic fermentation of organic material in digestion facilities [43, 44]. It does not contribute to the increase in atmospheric carbon dioxide concentrations because it comes from an organic source with a short carbon cycle and is a green solution in the development of sustainable fuels [43]. Furthermore, the digestion facilities can be constructed quickly in a few days using unskilled labor[45].

Biogas contains 50–70% methane and 30–50% carbon dioxide, as well as small amounts of other gases and typically has a calorific value of 21–24 MJ/m^3 [1, 44, 46]. Based on chemical analysis, the composition of the biogas produced in East Java is 66.4% methane, 30.6% carbon dioxide and 3% nitrogen [43] .

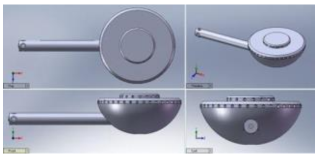
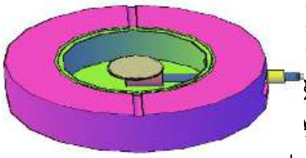
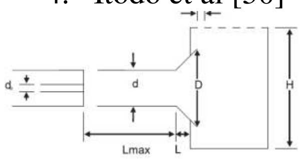
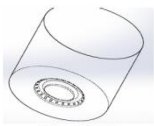
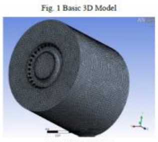
The biogas stove for cooking of the community food was designed and developed. The step wise procedure for design, development, and evaluation of biogas powered cook stove has been discussed as follows.

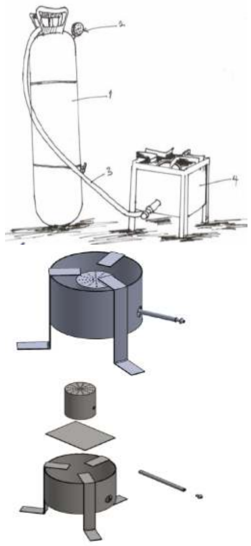
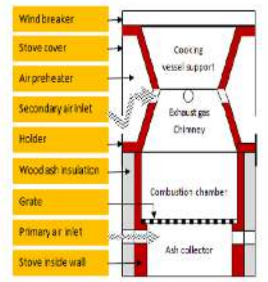
There are a number of studies [28, 30, 47-55] that focused on the Design and Developed a biogas burner. The main aims of such researchers were enhancing the performance of the biogas stove and in order to reduce fuel wood dependency. But their design methodology, parameters and construction materials were different from each other. Various design parameters were taken into account for efficient design such as air requirement for complete combustion, injector orifice, primary aeration, flame port, and mixture tube and throat. Bezuayehu et al [47] and Dejene et al [48] Designed, Optimization and CFD Simulation of Improved Biogas Burner for ‘Injera’ Baking in Ethiopia. During design of burner they could take several parameters such as size of orifice, throat size, burner port, diameter of jet, length of air intake hole, length of mixing pipe, number of diameter of flame port holes, height of the burner head. But they have several limitations during material selection as well as burner design. And also a small size burner was designed, for this reasons heat distribution through the baking pan is not uniform. This causes unequal distribution of heat on injera baking Mitad. Asfafaw et al [28] conducted solar powered heat storage for injera baking. Prototype for direct steam based baking was developed, tested in MU; phase change material based heat storage prototype was developed and tested. [50]

Obada et al [56] has designed constructed and evaluated the performance of biogas burner. The work geared towards modification and the improvement of biogas burners and their efficiency. The performance of the stove was evaluated by the process of boiling water. The efficiencies of the stove in water boiling and rice cooking were 21%, and 60% respectively.

Shewangizaw et al [49] Designed, Manufactured and Evaluated the performance of a biogas stove specifically for traditional Areka distillation. The work geared to analytically designing the biogas stove for minimum gas consumption and high efficiency, fabrication and experimental testing was done. Additionally the economic projection of biogas utilization in Areka distillation was evaluated. The performance of the stove evaluated through Water Boiling Test (WBT) and controlled cooking methods. The overall efficiency of the stove through water boiling testing were 54.8% and 43.6% at higher flame intensity and relatively lower flame intensity respectively, and the efficiency of the stove in controlled cooking was 27.7% reduction of fuelwood consumption.

Table2. 5 Types of biogas stoves

Types of biogas stove and burner	Title	Aim	Methodology	Remark
1. Bezuayehu et al[47] 2017 	Design, Optimization and CFD Simulation of Improved Biogas Burner for 'Injera' Baking in Ethiopia	+ Enhancing its performance	+ Analytical design analysis +Geometrical design using solid work bench design tool +CFD analysis using solid work bench design tool	+No experimental work +High fuel consumption on the burner + Low heat transfer through the stove
2. Dejene et al [48] 	Design of Biogas stove for Injera Baking Application	+Designed gas burner is used to supply pressure equally on the holes of the burner port	+ Analytical design analysis +CFD analysis using solid work bench design tool	+lack of equal biogas distribution on the baking pan
3. Shewangizaw et al [49] 	Design, fabrication and testing of biogas stove for 'Areka' distillation	+Reduction of fuel wood dependency	+Analytical y design the biogas stove +Developed a lab scale stove for distillation +Experimental testing using water boiling test	+ Stove construction is not proper +Heat loss + Lack of equal pressure distribution
4. Itodo et al [50]  Fig: diagram of burnr	Performance evaluation of biogas stove for cooking in Nigeria	Evaluating the performance of biogas stove by water boiling, cooking rice and beans	+analytically design the stove +experimental test was done by utilizing d/f instruments	+Cannot clearly shows the biogas stove construction and working principal
5. Prashant et al [51]  Fig. 1 Basic 3D Model  Fig. 2 Mesh Model	Analysis of burner for biogas by computational fluid dynamics and optimization of design by genetic	+To design burner suitable for domestic cooking. w/h will use biogas as a fuel	+Computational fluid dynamics is used to simulate combustion of biogas on burner +genetic algorism is used to	+Numerical simulation results verified with other researches +This technology is very less costly +Development of

	algorithm		optimize design of burner	such burner leads to more efficient use of biogas without its waste
6. David et al [52] 	Design and construction of a biogas burner	Reduction of fuel wood dependency	+Bernoulli's theorem was used to drive the flow rate of gas +Designing main components of burner +Experimentally tested the performance of the stove using water boiling test	+ Heat is lost to the surrounding b/c the flame cannot be bounded by an additional insulation. for these reason the cooking time was large and much fuel could consumed
7. Dessie et al [53]  *Figure 1. Schematic diagram of the new stove*	Design, manufacturing and performance evaluation of house hold gasifier stove	Identification and evaluation of technical and economical limitation of house hold biomass gasifier stoves manufactured and distributed in Ethiopia	+ Designing a family size standard gasifier stove +manufactured the stove + Evaluate the performance efficiency of the newly designed house hold gasifier stove	Do not offer good control of cooking rate , too short chimney
8. Kurchania et al [57] 	Design and performance evaluation of biogas stove for community cooking application	Design and develop a community biogas stove for baking (bread) or other food items on a hot plate for community purposes.	+Numerically analyzed biogas stove and burner +Performance of stove was evaluated by using a 25m^3 floating type biogas plant	

As shown from the above discussion in literature review section, injera baking stove technologies from early to recent time was discussed briefly. A number of researchers were intended to design and developed different types of injera baking stoves. Still now in rural area of developing countries because of lack of grid electricity network people especially children's prepares their daily food by using biomass fuel. This fuel causes several problems for peoples such as deforestation, GHG emission, environmental pollution, health problems etc.… to avoid and minimizes these problems a number of researchers were design biogas based injera baking stoves. However, previously implemented biogas injera baking stoves having the main problem of poor heat distribution through the baking pan, high biogas consumed and heat loss. So in this study by designing and developing tubular type burner and by considering different improvement techniques in order avoid or minimized the addressed problems caused by biomass fuel.

Chapter Three

3. Methodology and Materials

This study was conducted in keyet woreda, Amhara Regional State, South Shewa zone. The city is located approximately 170 km from Addis Ababa.

The present work seeks improvement on the existing designs by making the following design considerations: increasing the heat transfer area by designing tubular burner, enhancing the combustion process by providing for means of introducing sufficient air for combustion, and further reducing the amount of heat loss from the combustion chamber by insulating with the mixture of gypsum and brick. In this section, method of designing the newly developed biogas based injera baking stove, method of fabrication and method of experimental test is discussed briefly. During designing the biogas stove take several parameters as an input and processed by designing the stove based on the input parameters finally get the output or results. Fabrication of the newly developed biogas injera baking stove was developed based on the analytical design of the stove. During fabrication process a number of equipment was taken for construction of the biogas stove such as sheet metal, flat iron, angel iron, CHS, RHS, gypsum, brick. In addition to these, during fabrication process a number of Machin devices were used. During experimental test different types of measuring instruments were taken like Infrared thermometer, Bimetallic thermometer, K-Type thermometer, PT 100 thermometer and Gas flow meter.

Flow chart of research methodology

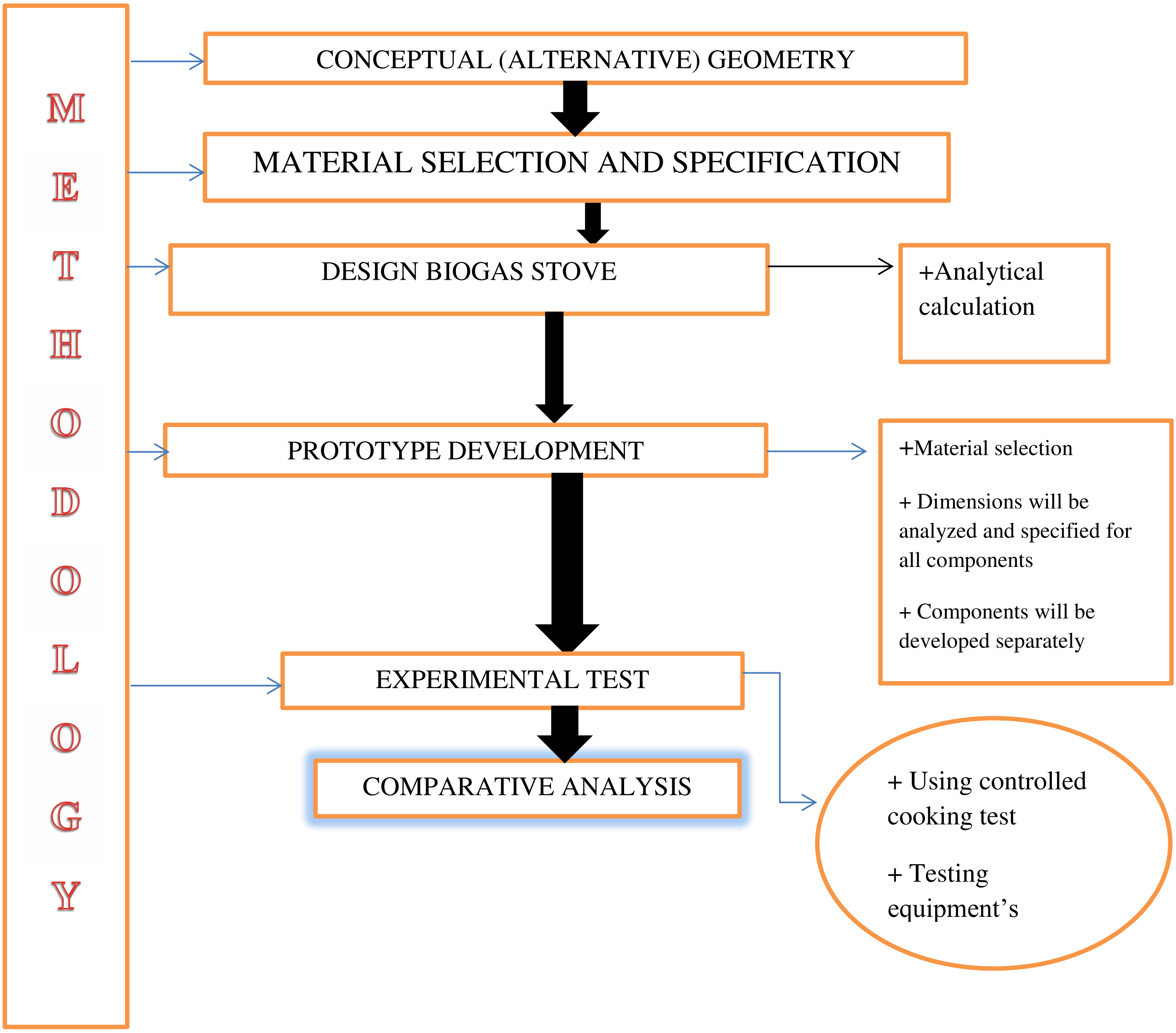


Figure3. 1 Flow chart of research methodology

3.1 Conceptual (alternative) Geometry

These conceptual alternative geometries are essential for selecting the best burner for injera baking application. Early researchers were conducted and investigating the biogas burner but, previously implemented biogas burners were the problem of uniform heat distribution through the baking pan because of poor construction of burner. So in this section different alternative geometries are listed and briefly discussed based on different parameters. After that select the best alternative and design, develop and evaluate the performance of the stove.

The alternative burner's geometry could be discussed based on the following parameters:

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

3.1.1 Bar type tubular burner with a number of parallel hollow

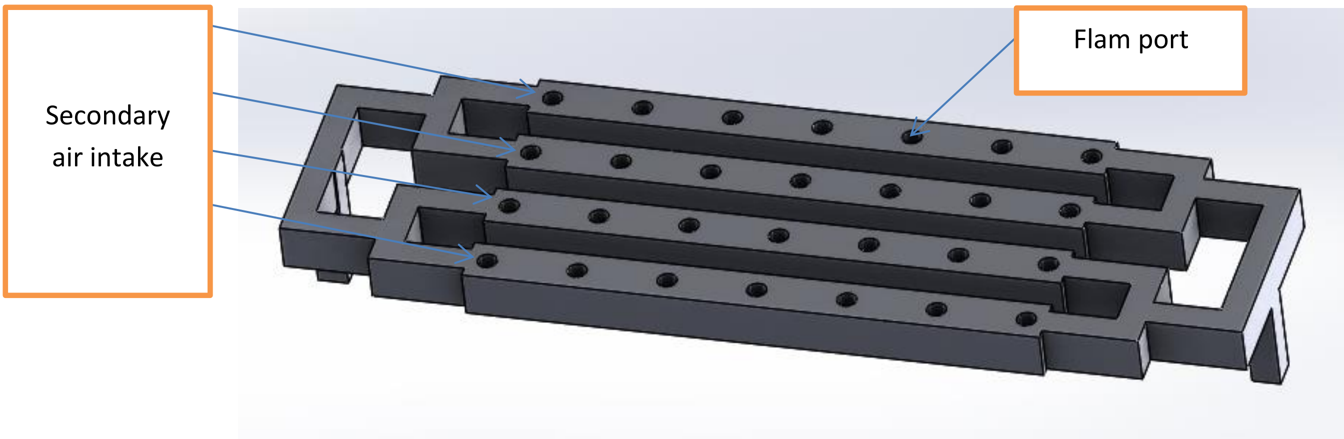


Figure3. 2 Bar type tubular burner with a number of parallel flam port

Figure 3.2 show bar type tubular burner with a number of parallel flame ports. As shown in the figure above the secondary air intake is parallel to the flame port and the air could be entering in to the combustion chamber in right and left side of the burner. In this type of flame port the secondary air is unable to reach holes at center. This flame port pattern on a burner would produce a poor burning pattern, with the flames from the central burner ports being much higher than those at the edge because secondary air is prevented from reaching them [58]. Based on pressure drop, the biogas distribution through the burner hole should be uniform. Also because of poor flame port pattern the temperature distribution through the baking pan should be not uniform. This type of burner is also easy to manufacture.

3.1.2 Tubular burner with a number of zigzag hollow

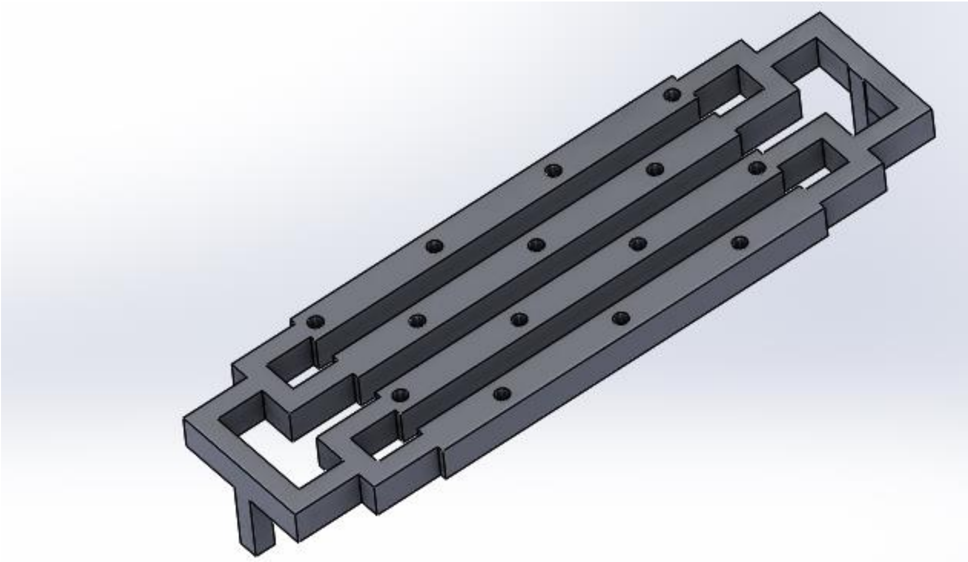


Figure3. 3 Tubular burner with a number of zigzag flam ports

Figure 3.3.Shows tubular burner with a number of zigzag flame port pattern. As shown in the figure above the secondary air intake is parallel to the flame port and taken in to the flame in right and left side of the burner. In this type of flam port arrangement the Secondary air is able to reach at all holes. This pattern allows air to reach each of the burner holes[58]. The pressure of gas also distributed equally through the burner port and also the flame temperature through the baking pan must be uniform. In addition, this type of burner is easy to manufacturing.

3.1.3 Spiral type burner pattern

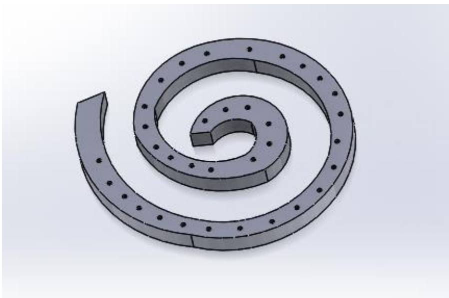
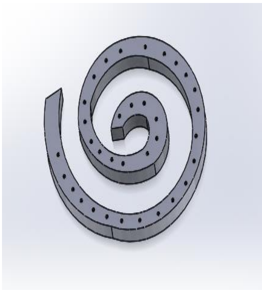
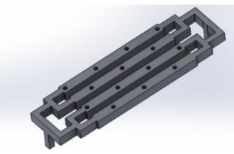


Figure3. 4 Spiral type burner

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.

Table3. 1summery table of alternative geometry

Alternative geometries	Name of geometry	Pressure drop	Flam port pattern	Temperature distribution	Machinability	Remark
	Tubular (bar type) burner with double injector	Pressure of gas distributed equally	Poor	Poor, b/c of flam port pattern	Easy	The flam port pattern is poor
	Spiral burner	Highly pressure drop	Good	Poor, b/c of pressure drop	Complex	The pressure of gas will be decreases at the center and it is complex for machinability
	Tubular (bar type) burner	Pressure of gas distributed equally	Good	Uniform distribution	Easy	It is better geometry than the other

Among the above geometries, tubular (bar type) burner with a number of zigzag flam port patterns was selected for designing biogas injera baking stove.

3.2 Material selection

Gas burner components are made up of different materials depending up on the properties of the material. Cast Iron, Miled steel, Aluminum and Copper tube are the most common types for biogas burner construction materials. Thermal conductivity and melting points are the main parameters in order to select the best alternative material for biogas burner.

Table3. 2 Burner construction material and its thermal conductivity

Materials	Thermal conductivity W/mK	Melting point (^{o}c)
Mild steel	20	1,427
Aluminum	205	660
Copper	385	1084
Cast iron	20	1127-1204

Table 3.2 show burner construction materials and its thermal conductivity and melting point. As shown from the above table Mild steel is the best alternative because: it has a good melting point is not brittle material, it is easily welded and also it is cheaper than other materials. However the Mild steel is susceptible to corrosion so in order to avoiding this problem, must be coated with corrosion inhibitor that cans with stand the temperature in which the steel is being used. For this study the burner construction material is Mild steel.

Insulation material:

Thermal conductivity of a material is its ability to conduct heat. Materials with lower thermal conductivity are used for insulation purpose where we need less heat transfer. For this study the mixture of brick and gypsum should be selected for insulation purpose. Common red bricks have a thermal conductivity of 0.6 $Wm^{-1}K^{-1}$. For insulating bricks, the value is even lower 0.15 $Wm^{-1}K^{-1}$ [59].

Table3. 3 Over all Biogas Stove Construction Material and Measuring instrument

Stove construction material		Measuring instrument	Materials needed for experiment
Parts of stove	Construction Materia;		
Tubular burner	Mild steel	Infrared thermometer	Teff dough
Orifice	Brass	Weighing balance	Plastic vessel
Throat	Mild steel	Gas flow meter	Metal trey
Support(leg)	Square RHS tube	K-type thermometer	
Combustion chamber	A mixture of brick and gypsum	stop watch timer	
Outer part of combustion chamber	Aluminum	Pressure gauge	
Valves	Plastic	PT-100 thermocouple	
Mitad	Clay	Multimeter	

		Bimetallic thermometer	

3.3 Methods Used For Designing Biogas Injera Baking Cook Stove

Design procedure

I. Estimate Energy demand for injera baking
II. Estimate the biogas flow rate
III. Calculate the air requirement for complete combustion
IV. Determine the size of injector orifice or jet
V. Design the throat or mixing chamber
VI. Determine the diameter of burner port and the number of burner port
VII. Estimate the Number of Flam Port
VIII. Flam Height Determination
IX. Heat Transfer Analysis of the stove
X. Determine the thickness of insulation

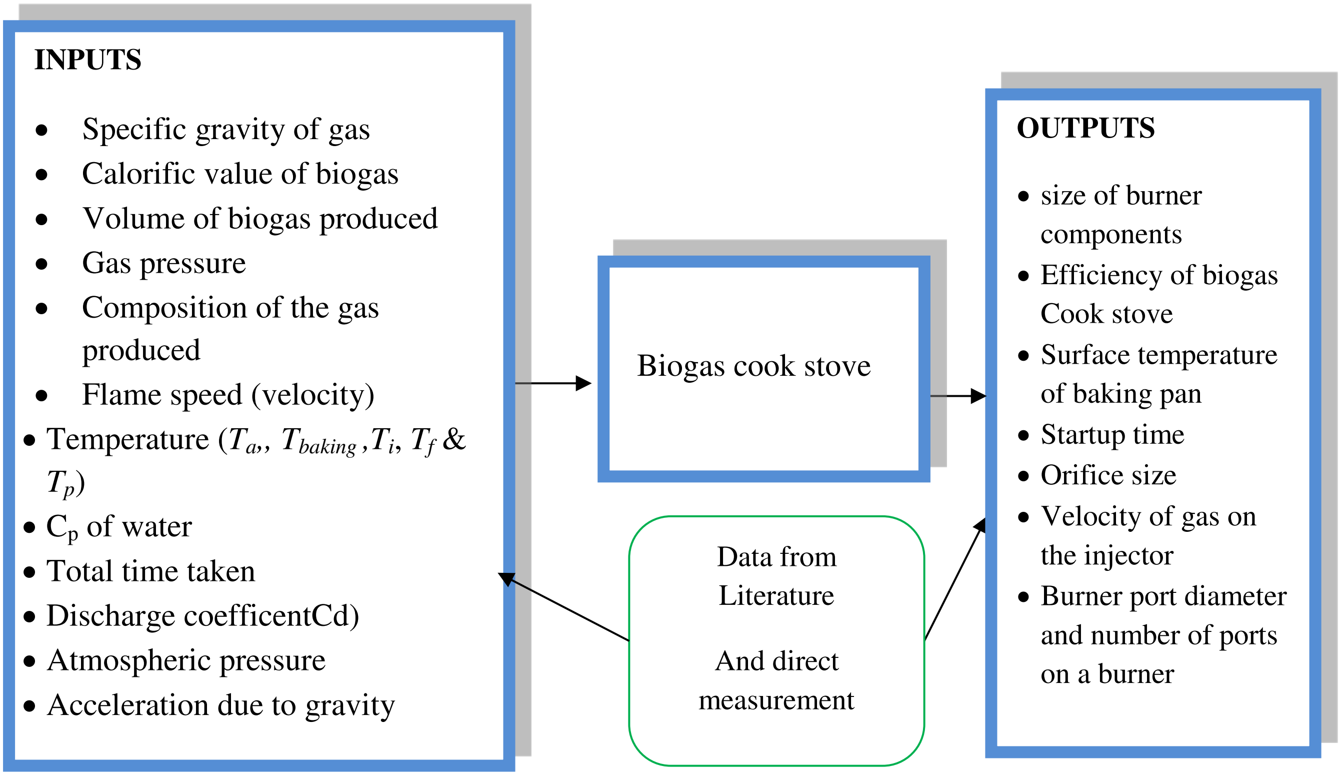


Figure3. 5 Design parameters of biogas burner

3.4 Methods Used For Fabrication of Improved Biogas Injera Baking Stove

Method of fabrication

- Materials were selected for each component of the stove according to their thermal resistance required.
- Dimensions were analyzed and specified for all components
- Parts/components were manufactured separately
- Assembling
- Painting or other esthetic can be completed

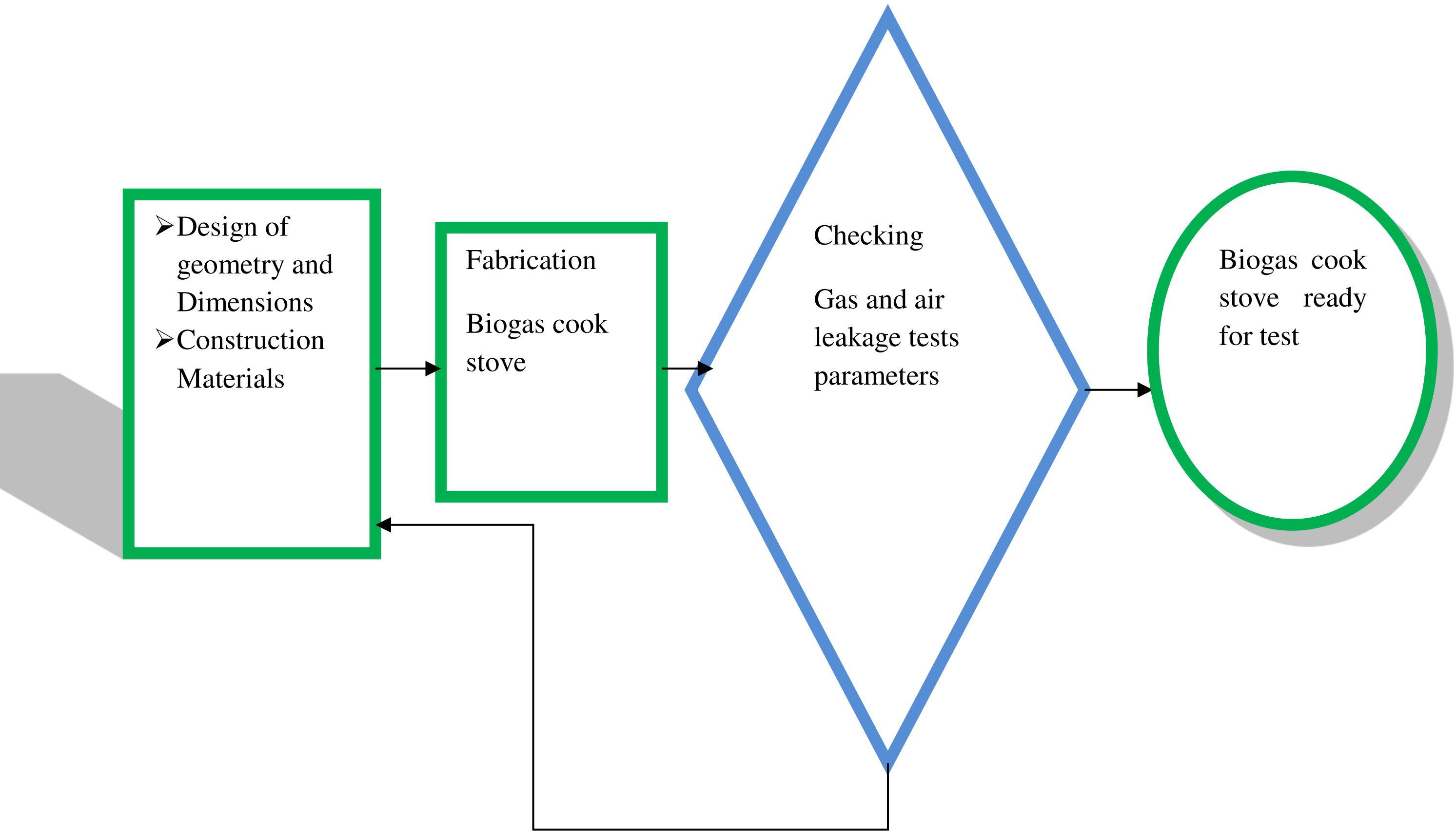


Figure3. 6 Manufacturing work flow diagram for improved biogas injera baking stove

3.5 Methods of Experiment

The performance evaluation of biogas injera baking stove was experimentally tested in keyet woreda. The city is located approximately 170km from Addis Abeba. The experiment was done in two stages namely the existing biogas injera baking stove and the newly developed stove. The performance evaluation of the biogas stove also carried out by controlled cooking test method. During the experimental testing of CCT a number of measuring instruments and equipment were used. Amount of biogas consumption, temperature, quality of injera, cooking time and efficiency are the main parameters to evaluate the performance of existing and newly developed biogas injera baking stove

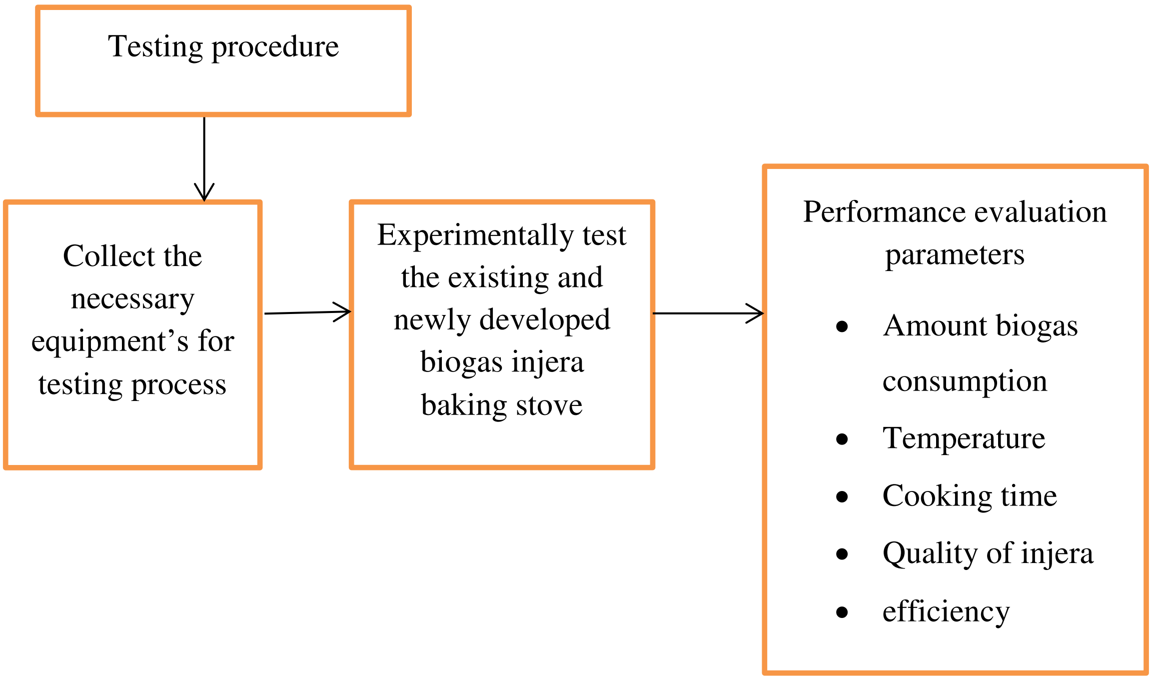


Figure3. 7 General procedure for evaluate the performance of stove

3.5.1 Testing 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 existing and new 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 ignited the 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 by three different measuring instruments such as PT-100 Thermocouple connected with digital multimeter, K-Type thermocouple connected with digital multimeter and Bimetallic thermometer.
- 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

means the time when the last injera is removed off the Mitad, the time to bake each enjera, the time to heat the Mitad before the next was going to be baked and finally the total cooking time of the existing and new biogas injera baking stove was recorded.

- The amount of biogas consumption during baking process was measured by gas flow meter which is connected with biogas supply hose.
- Finally compared the quality of injera that can be baked by the Existing and newly developed biogas injera baking stove.
- The efficiency of new biogas injera baking stove was determined.

3.5.2 Controlled cooking test (CCT)

Controlled cooking test (CCT) method is used to evaluate the performance of Injera baking stove. It is chosen for its suitability for Injera baking operation. The CCT is a standard cooking test which is designed for field test that measures the performance of improved stove relative to the common or traditional stoves when cook prepares a local meal. It analyzes how the improved stove performs to save fuel and time compared to common or traditional cooking methods. Similarly, in this work it was designed to use CCT for testing the performance of biogas Injera baking stove. Then all biogas stove will be compared as they perform a standard baking task that is similar to the actual baking that local people do every day.

It is used to assess the performance according to Injera baking situation in a controlled setting using local fuels, and local practice. The tests are designed in a way that minimizes the influence of other factors. All of the tests was conducted by same Injera baking Mitad which is local made from clay.

3.5.3 Performance evaluation of the stove

The performance evaluation was carried out by injera baking. The time taken for the various tasks was determined from a stop watch. The cooking rate (Cr) and the efficiency of the stove (Sasse, 1988) were calculated using equation below.

$$C_r = \frac{qty\ of\ commodity}{time\ taken} \qquad (3.1)$$

$$\eta = \frac{C_r}{Q} * 100\% \qquad (3.2)$$

Chapter Four

4. Design and Fabrication

4.1 Design

4.1.1 Energy demand determination

To estimate the energy demand that needed to bake an injera from ambient temperature to heating the temperature is given by [49]:

Specification

The following specifications are essential for determining energy demand.

- ✓ Weight of dough that is needed for baking one injera = 581gm=0.581 kg [48]
- ✓ Dough contains 60% of water and 40% of Teff flour [48] then

  Mass of water = 0.6 × mass of dough

  = 0.6 × 0.58kg

  = 0.348 kg of water

  Mass of Teff = 0.4 ×mass of dough

  = 0.4 × 0.6kg

  = 0.232 kg of Teff

  Mass of dough= mass of water + mass of teff
- ✓ From [29], the optimum baking temperature is in between (180°c -200°c) then on average take the baking temperature (T_2) =190°c
- ✓ The boiling temperature of water at local atmospheric pressure = 100°c
- ✓ Ambient temperature = 21°c
- ✓ Specific heat of water at 21°c = 4.174KJ/kg °c [60]
- ✓ Specific heat of Teff at 21°c = 1.046kJ/kg °c [60]
- ✓ $C_{P,dough}$=5.22 kJ/kg °c [48]
- ✓ The estimated time to bake 1 injera is = 2.5min =150sec [48]
- ✓ A typical baking of Mitad is 60 cm in diameter
- ✓ The calorific value of biogas is developed from [48]

The desired output power for baking injera on a Mitad is calculated as [48]

The amount of energy needed to convert 0.581kg of teff dough at a temperature of 21°c in to steam at 100°c is determined by:

$$p_{out} = m_{,dough} \times C_{P,dough}(T_2 - T_1) \quad (4.1)$$

$$p_{out} = 0.581kg \times 5.22kJ/kg(100 - 21)$$

$$p_{out} = 239.59KJ$$

The amount of energy needed in kW is given by, dividing the above result to the time that bake a single injera which is 150 sec

$$p_{out} = \frac{239.59KJ}{150sec}$$

$$p_{out} = 1.597KW$$

- ❖ The required input power from flam combustion to bake an injera is:

$$\eta = \frac{p_{out}}{p_{required}} \quad (4.2)$$

$$p_{required} = \frac{p_{out}}{\eta} \quad (4.3)$$

From [48], the maximum efficiency of biogas stove is 55%,

$$p_{required} = \frac{1.597KW}{0.55}$$

$$p_{required} = 2.904kW$$

4.1.2 Estimate the biogas flow rate

- ❖ The volume flow rate of biogas (Q_{gas}) also given by [58]:

$$Q_{biogas} = \frac{Energy\ nedded}{Calorific\ value} \quad (4.4)$$

$$Q_{gas} = \frac{10.454\text{MJ/hr.}}{22MJ/m^3}$$

$$Q_{biogas} = 0.475m^3/hr$$

4.1.3 Calculate the air requirement for complete combustion

The Biogas fuel will burn over a fairly narrow range of mixtures from 9% to 17% biogas in air [49]. If the flame is “too rich”, and has too much fuel, then it will burn badly and incompletely, giving carbon monoxide (which is poisonous) and soot (carbon particles). So for complete combustion the following biogas composition must be needed. In partially aerated burners, air is mixed with the gas before it is burnt. The amount of primary air added to the gas before the flame, varies depending up on the design of burner, but is usually around 50% of the total air requirement[48].

Biogas composition

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

One volume of methane requires two volumes of oxygen, to give one volume of carbon dioxide and two volumes of steam.

Since there is 60% methane in biogas and 21% oxygen in air [48]:

$\frac{1}{0.6} = 1.67$ Volumes of biogas require $\frac{2}{0.21} = 9.52$

Or, 1 volume of biogas requires $\frac{9.52}{1.67} = 5.7$ volume of air or $\frac{1}{1+5.7} = 0.1492 = 15.3\%$ biogas in air (stoichiometric air requirement)

Table4. 1 Properties of biogas for designing stove[53]

Property	Value
Methane and carbon dioxide content	60% and 40%
Calorific value	(21-24)MJ/m^3
Specific gravity	0.94
Density	1.2kg/m^3
Flame speed factor	11.1
Air requirement for combustion in 1 volume of biogas	5.7m^3/h
Combustion speed	40cm/sec
Inflammability in air	6-25%

4.1.4 Determine the size of injector orifice or jet

On a burner the amount of the gas is controlled by the size of injector orifice or jet. It is a hole in a plate. Also it is constructed from different material but for this study, injector is made from a brass thimble with a hole drilled in the end, and screwed on to the end of gas line fitting, so that it can be easily replaced. The important role of the injector orifice is separate the burner from the gas supply pipe. In this study also there are two injectors for supplying the gas from digester to mixing chamber.

The size of the injector orifice could be determined as follow:

The jet or injector orifice diameter was calculated from empirical version of Bernoulli's theorem which defines the gas flow rate through an injector orifice (jet) [48]

$$Q_{biogas} = 0.0467 C_d A_j \sqrt{\frac{P}{\rho_{substance}}} \qquad (4.5)$$

Where:

Q_{biogas} = Gas flow rate (m^3/h),

A_j = Area of orifice (mm2)

$A_j = \pi d^2/4$

p = gas pressure before orifice (mbar)

$\rho_{substance}$ = Density of substance

Cd = coefficient of discharge for the orifice

- Coefficient of discharge for the orifice taken into accounts the friction losses and vena contractor through the orifice. It usually has a value between 0.85 and 0.95 Assuming suitable injector with a Cd of 0.94 including the vena contractor and friction losses through the orifice and a gas supply pressure of 8 mbar,
- Density of a substance such as density of methane and Carbon dioxide (with air density (reference density) =1kg/m^3) is 0.554kg/m^3 and 1.519kg/m^3 respectively Volumetric content of biogas is 60% methane and 40% carbon dioxide; based on the volumetric content specific gravity of biogas expressed as[47]:

$$\rho_{substanc} = (0.554\, kg/m^3 \times 60\%) + (1.519\, kg/m^3 \times 40\%)$$
$$= 0.94\, kg/m^3$$

$$S = \frac{\rho_{substanc}}{\rho_{reference}}$$

$$S = \frac{0.94\, kg/m^3}{1\, kg/m^3} = 0.94$$

$$Q_{biogas} = 0.0467 C_d A_j \sqrt{\frac{P}{\rho_{substanc}}}$$

$$Q_{biogas} = 0.0467 C_d \pi dj^2/4 \sqrt{\frac{P}{\rho_{substanc}}}$$

$$d_j{}^2 = \frac{Q_{biogas}}{0.0366 C_d \sqrt{\frac{P}{\rho_{substanc}}}} \tag{4.6}$$

$$d_j{}^2 = \frac{0.475 m^3/h}{0.0366 \times 0.94 \times \sqrt{\frac{8mbar}{0.94\, {}^{kg}/_{m^3}}}}$$

$$d_j = \sqrt{\frac{0.475}{0.0366}} \times \sqrt[4]{\frac{0.94}{8}}$$

$d_j = 4.59mm \approx 5mm$, and the area of jet also determined as follow:

$$A_j = \frac{\pi d_j{}^2}{4} \tag{4.7}$$

$$A_j = \frac{\pi \times (5mm)^2}{4}$$

$$A_j = 19.6mm^2 \approx 20mm^2$$

- Determine the velocity of gas in jet of injector orifice

The velocity of gas in the injector orifice in (m/s) could be given by equation (4.8)

$$V_j = \frac{Q_{gas}}{3.6 \times 10^3 \times A_j} \tag{4.8}$$

$$V_j = \frac{0.475}{3.6 \times 10^3 \times (4 \times 10^{-4})}$$

$$V_j = 0.86m/s$$

4.1.5 Design of Throat (Mixing Chamber)

The mixture of primary air that comes from atmosphere and the biogas that comes from the injector enters at the end of the mixing tube in the region of throat or mixing chamber. The primary aeration is depending up on the entertainment ratio; which is determined by the area of the throat and the injector.

$$r = \sqrt{s}\left(\sqrt{\frac{A_t}{A_j}} - 1\right) = \sqrt{s}\left(\sqrt{\frac{d_t}{d_j}} - 1\right) \quad (4.9)$$

Where:

r = Entertainment ratio

s = Specific gravity of gas

A_t = Area of throat

A_j =Area of jet

d_t= Diameter of throat

d_j= Diameter of jet

For designed biogas burner 40-60% of primary aeration is needed.

For bar type burner the entertainment ratio r is (2-2.5) [8], so for this study take the average entertainment ratio, i.e r = 2.25.

By using prigs formula to find out the diameter of the throat:

$$d_t = \left(\frac{r}{\sqrt{s}} + 1\right) d_j \quad (4.10)$$

$$d_t = \left(\frac{2.25}{\sqrt{0.94}} + 1\right) 5$$

$$d_t = 16.6mm \approx 20mm$$

Area of throat is given by equation (4.11)

$$A_t = \frac{\pi {d_t}^2}{4} \quad (4.11)$$

$$A_t = \frac{\pi \times (20mm)^2}{4} = 314mm^2$$

4.1.6 Determine the velocity of gas in the throat

The diameter of throat is much larger than the diameter of injector orifice or jet. So the velocity of gas is much reduced in a throat.

The velocity of gas in a throat is given by [48]:

$$V_t = V_j\left(\frac{A_j}{A_t}\right) = V_j\left(\frac{{d_j}^2}{{d_t}^2}\right) \quad (4.12)$$

$$V_t = V_j\left(\frac{{d_j}^2}{{d_t}^2}\right)$$

$$V_t = 0.86\left(\frac{5^2}{20^2}\right)$$

$$V_t = 0.0537m/s$$

4.1.7 Determine the pressure of gas in throat

The pressure of gas is in throat is given by[48]:

$$P_t = P_o - \rho\frac{{V_j}^2}{2g}\left[1 - \left(\frac{d_j}{d_t}\right)^4\right] \quad (4.13)$$

Where, P_O is the atmospheric pressure which is 10^5, ρ density of gas = 1.0994, acceleration due to gravity (g) = 9.81m/s^2

$$P_t = 10^5 - 1.0994 \times \frac{0.86^2}{2 \times 9.81}\left[1 - \left(\frac{5}{20}\right)^4\right]$$

$$P_t = 10^5 - 0.0412$$

$$P_t = 99.99 \times 10^3 pa$$

4.1.8 Determine the flow rate of the mixture in the throat

The flow rate of mixture in the throat also given by [48].

$$Q_m = \frac{Q_{gas}(1 + r)}{3600} \quad (4.14)$$

$$with\ Q_m\ in \frac{m^3}{s}, Q_{gas}\ in \frac{m^3}{hr}$$

$$Q_m = \frac{1.245(1+2.25)}{3600}$$

$$Q_m = 0.0011\, {}^{m^3}/_{s}$$

4.1.9 Determine the pressure drop in the throat

In throat, the pressure drop due to the flow of the mixture down the mixing tube should be checked, by first calculating the Reynolds number [48].

Step 1: Estimate the Reynold number

$$R_e = \frac{\rho d_t V_t}{\mu} = \frac{\rho d_t}{\mu} \times \frac{4Q_m}{\pi d_t} \tag{4.16}$$

$$R_e = \frac{4\rho Q_m}{\pi d_t \mu}$$

Where ρ and μ are the density and viscosity of the mixture respectively.(use ρ= 1.15kg/m^3 and μ= 1.17×10^{-5} pa s @ 30^{o}c).

$$R_e = \frac{4 \times 1.15 \times 1.1 \times 10^{-3}}{\pi \times 0.02 \times 1.17 \times 10^{-5}}$$

$$R_e = 6886.6$$

The required Reynold number is above 2000, i.e $R_e > 2000$ then the pressure drop is given by:

$$\Delta P = \frac{f}{2}\rho {V_t}^2 \frac{L_m}{d_t} = \frac{f}{2}\rho \frac{16{Q_m}^2}{\pi^2 {d_t}^5} L_m \tag{4.17}$$

Where: $f = \frac{64}{R_e}$, when $R_e < 2000$ and,

$f = \frac{0.316}{{R_e}^{0.25}}$, when$R_e > 2000$,

$$f = \frac{0.316}{6886.6^{0.25}}$$

$$f = 0.035$$

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

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

$$\Delta P = \frac{f}{2}\rho\frac{16{Q_m}^2}{\pi^2{d_t}^5}L_m$$

$$\Delta P = \frac{0.035}{2} \times 1.15 \times \frac{16 \times (1.1 \times 10^{-3})^2}{\pi^2(0.02)^5} \times 0.3$$

$\Delta P = 3.68pa$, This is much lower than the driving pressure in the throat.

4.1.10 Design of Burner Flam Port

When a biogas/air mixture has ignited, the flame front produced propagates through the remaining unburnt gases at a rate dependent on the mixture composition, pressure and temperature. The burning velocity is a fundamental property of the mixture and is linked to the overall chemical reaction rate in the flame. Burning velocity is defined as the velocity normal to the flame front, relative to the unburnt gas, at which an infinite one dimensional flame propagates through the unburnt gas mixture. Biogas has a stoichiometric flame speed of only 0.25 m/s burning velocity[48].

The mixing supply velocity V_p is given by [48]

$$V_P = \frac{Q_m}{A_p} < 0.25\, m/s \tag{4.19}$$

Where: A_p- (the total burner port area in m^2) $= n_p\frac{\pi{d_p}^2}{4}$

n_p- Number of ports

d_p- Diameter of port in m

$$A_p > \frac{Q_m}{0.25}$$

$$A_p > \frac{1.1 \times 10^{-3}}{0.25} > 0.0044m^2$$

Using 3mm diameter holes, the total number required will be:

$$n_p = \frac{4A_p}{\pi{d_p}^2} \tag{4.20}$$

$$n_p = \frac{4 \times 0.0044}{\pi \times 0.003^2}$$

$n_p = 622.78$, It is the total number of port, but they have 9 numbers of bars on a burner so divided this number in to 9

i.e $n_p = \frac{622.78}{9} = 69.1 \approx 69$

Using the flame stabilization, it should be possible to reduce this number of burner ports, by up to 1/2, so the total number of flam ports on a burner having 311.39 and the burner consisted have 9 numbers of tubular bars. Then divide 311.39 to 9 it gives the number of flam ports on a single tubular bar which is 34.59 approximately 35 holes on a single bar. Each has 3mm diameter.

4.1.11 Flam Height Determination

The flame height (H_f) be related to the required input power ($P_{required}$) with diameter of flame D_f. The calculation of flame length is as follows:

$$H_f = 0.235{P_{requird}}^{2/5} - 1.02D \quad (4.21)$$

Where $P_{requird}$ is given by KW and D_f is diameter of flam port

The flame length is determined as follows. $P_{requird}$ is determined above by equation(4.3) and is

$$p_{required} = 2.904kW$$

The total number of burner flam port is 311.39 and for a single hole, which has a diameter of 3mm, then the heat released rate($p_{required}$) for one hole becomes:

$$\frac{2.904kw}{311.39} = 0.0093kw$$

$$H_f = 0.235{P_{requird}}^{2/5} - 1.02D_f$$

$$H_f = 0.235 \times (0.0093)^{2/5} - 1.02 \times 0.003$$

$$H_f = 0.0329m$$

$$H_f = 32.9mm \sim say\ 33mm = 3.3cm$$

4.1.12 Heat Transfer Analysis

Heat transfer analysis of injera baking stove is discussed in the following sections, but in this section introduction about heat transfer, mechanism of heat transfer, heat loss and available data's for analytical calculations is discussed.

Heat transfer is the determination of rate of energy transfer which is the form of energy that can be transferred from one system to another form as a result of temperature difference so, the basic requirement for heat transfer is the presence of a temperature difference. There can be no net heat transfer between two mediums that are at the same temperature. The rate of heat transfer in a certain direction depends on the magnitude of the temperature gradient (the temperature difference per unit length or the rate of change of temperature) in that direction. The larger the temperature gradient, the higher the rate of heat transfer.

Heat can be transferred in the three different modes such as conduction, convection, and radiation. These all modes of heat transfer require the existence of a temperature difference, and all modes are transferred heat from the high-temperature medium to a lower-temperature one.

- Conduction is the transfer of heat by direct contact between two solid materials.
- Convection is the mode of heat transfer between a solid surface and the adjacent gas or liquid that is in motion, and it involves the combined effects of fluid motion and conduction. The faster the fluid motion, the greater the convection heat transfers.
- Radiation is the energy emitted by matter in the form of electromagnetic waves as a result of the changes in the electronic configurations of the atoms or molecules. Unlike convection and conduction, the transfer of energy by radiation does not require the presence of an intervening medium. In fact, energy transfer by radiation is fastest (at the speed of light) and it suffers no attenuation in a vacuum.

4.1.12.1 Heat loss and heat transfer characteristics of injera baking pan

Heat can be lost in three directions of injera baking stove. These are top, bottom and on lateral side of the baking pan. The stove uses all three fundamental mode of heat transfer such as conduction, convection and radiation. The bottom surface of injera is heated by conduction and a little part of heat is transferred to its upper surface by means of convection and radiation.

4.1.12.2 Heat transfer through the wall of an insulated material

Heat loss through the insulated stove of cylindrical pipe is determined as follows. Insulated materials are the combination of gypsum and brick. It covered the wall side of the biogas injera baking stove. This mixture has a thermal conductivity of 0.15w/m^{2}k [59].

Assumption

- ✓ Assume steady heat transfer rate through the insulated layer.
- ✓ Inside and outside the combustion chamber assume convection and radiation heat transfer
- ✓ Thermal conductivity is constant.

Analysis

The thermal resistance network involves three resistances in series and is given in fig below.

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

$$A_1 = 2\pi r_1 L \tag{4.22}$$

$$\dot{Q} = UA\left(T_{\infty,i} - T_{\infty,o}\right) \tag{4.23}$$

$\dot{Q}$ is the heat flow across the face at r equals that r+Δr and U is the over all heat transfer coefficient and A the circumferential area of the cylinder.

$$\dot{Q} = \frac{T_{\infty,i} - T_{\infty,o}}{{}^{1}/_{UA}}$$

Where

${}^{1}/_{UA}$ is equivalent to the overall or the summation of thermal resistance network.

$$\frac{1}{UA} = \frac{1}{2\pi r_1 L h_{c,i}} + \frac{ln\left(\frac{r_2}{r_1}\right)}{2\pi K_A L} + \frac{1}{2\pi r_2 L h_{c,o}} \tag{4.24}$$

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

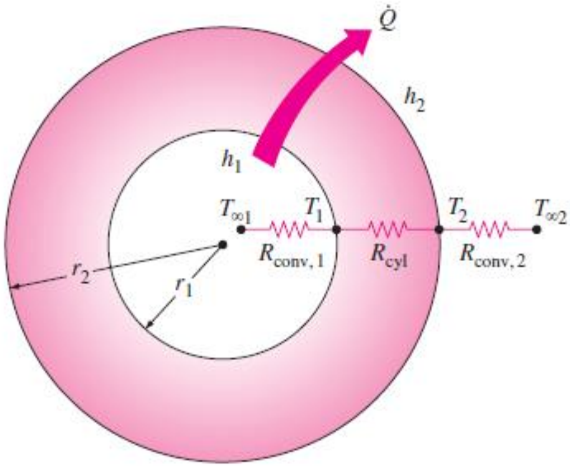


Figure4. 1 The thermal resistance network for a cylindrical shell subjected to convection from both the inner and the outer side

However, convectional heat transfer coefficient is calculated as follow:

$$h_c = \frac{N_u \times K}{L_n} \tag{4.25}$$

For vertical plate and heat flows in horizontal direction

$$N_u = 0.062(G_r)^{0.327} \tag{4.26}$$

$$G_r = \frac{g\beta\Delta T(L_n)^3}{\gamma^2} \tag{4.27}$$

Where,

L_n is the space between the flame and plate

K is thermal conductivity

ΔT is temperature difference between the two faces

β is volumetric coefficient of expansion of air

γ is kinematic viscosity

g is gravitational force

N_u is non-dimensional heat transfer coefficient

G_r is ratio of buoyant to viscous forces; replace Re in the cases of natural convection

From [48] ,By taking the convectional heat transfer coefficient$h_{c,i}$ = 5.674W/m^{2}k at internal combustion temperature of stove which is 400^{o}c and ambient temperature which is 21^{o}c, determine the outer convectional heat transfer coefficient $h_{c,o}$ =3.53W/m^{2}k and take 7cm space between the flame and plate.

By using equation (4.23) and (4.24) determine the heat flow through an insulated material by taking different alternative outer diameter dimension. Where, r_1= 29cm = 0.29m, thermal conductivity of an insulated wall is 0.15W/m^{2}k

Let: when the outer radius of an insulator r_2 in cm

r_2	29.5	30	30.5	31	31.5	32	32.5	32.75

Then by taking the above variables and get the heat flow rate

$$\dot{Q} = \frac{T_{\infty,i} - T_{\infty,o}}{\frac{1}{2\pi r_1 L h_{c,i}} + \frac{ln\left(\frac{r_2}{r_1}\right)}{2\pi K_A L} + \frac{1}{2\pi r_2 L h_{c,o}}} \quad (4.28)$$

@ r_2= 0.295m

$$\dot{Q} = \frac{400 - 21}{\frac{1}{2\pi \times 0.29 \times 0.07 \times 5.674} + \frac{ln\left(\frac{0.295}{0.29}\right)}{2\pi \times 0.15 \times 0.07} + \frac{1}{2\pi \times 0.295 \times 0.07 \times 3.53}}$$

$$\dot{Q} = \frac{379}{1.38 + 0.259 + 2.18}$$

$$\dot{Q} = 99.2W$$

@ r_2= 0.3m

$$\dot{Q} = \frac{400 - 21}{\frac{1}{2\pi \times 0.29 \times 0.07 \times 5.674} + \frac{ln\left(\frac{0.3}{0.29}\right)}{2\pi \times 0.15 \times 0.07} + \frac{1}{2\pi \times 0.3 \times 0.07 \times 3.53}}$$

$$\dot{Q} = \frac{379}{1.38 + 0.514 + 2.14}$$

$$\dot{Q} = 93.95W$$

@ r_2= 0.305m

$$\dot{Q} = \frac{400 - 21}{\frac{1}{2\pi \times 0.29 \times 0.07 \times 5.674} + \frac{ln\left(\frac{0.305}{0.29}\right)}{2\pi \times 0.15 \times 0.07} + \frac{1}{2\pi \times 0.305 \times 0.07 \times 3.53}}$$

$$\dot{Q} = \frac{379}{1.38 + 0.7647 + 2.113}$$

$$\dot{Q} = 89.01W$$

@ r_2= 0.31m

$$\dot{Q} = \frac{400 - 21}{\frac{1}{2\pi \times 0.29 \times 0.07 \times 5.674} + \frac{ln\left(\frac{0.31}{0.29}\right)}{2\pi \times 0.15 \times 0.07} + \frac{1}{2\pi \times 0.31 \times 0.07 \times 3.53}}$$

$$\dot{Q} = \frac{379}{1.38 + 1.011 + 2.075}$$

$$\dot{Q} = 84.86W$$

@ r_2= 0.315m

$$\dot{Q} = \frac{400 - 21}{\frac{1}{2\pi \times 0.29 \times 0.07 \times 5.674} + \frac{ln\left(\frac{0.315}{0.29}\right)}{2\pi \times 0.15 \times 0.07} + \frac{1}{2\pi \times 0.315 \times 0.07 \times 3.53}}$$

$$\dot{Q} = \frac{379}{1.38 + 1.254 + 2.045}$$

$$\dot{Q} = 81W$$

@ r_2= 0.32m

$$\dot{Q} = \frac{400 - 21}{\frac{1}{2\pi \times 0.29 \times 0.07 \times 5.674} + \frac{ln\left(\frac{0.32}{0.29}\right)}{2\pi \times 0.15 \times 0.07} + \frac{1}{2\pi \times 0.32 \times 0.07 \times 3.53}}$$

$$\dot{Q} = \frac{379}{1.38 + 1.492 + 2.013}$$

$$\dot{Q} = 77.58W$$

@ r_2= 0.325m

$$\dot{Q} = \frac{400 - 21}{\frac{1}{2\pi \times 0.29 \times 0.07 \times 5.674} + \frac{ln\left(\frac{0.325}{0.29}\right)}{2\pi \times 0.15 \times 0.07} + \frac{1}{2\pi \times 0.325 \times 0.07 \times 3.53}}$$

$$\dot{Q} = \frac{379}{1.38 + 1.728 + 1.98}$$

$$\dot{Q} = 74.48W$$

@ r_2= 0.3275m

$$\dot{Q} = \frac{400 - 21}{\frac{1}{2\pi \times 0.29 \times 0.07 \times 5.674} + \frac{ln\left(\frac{0.3275}{0.29}\right)}{2\pi \times 0.15 \times 0.07} + \frac{1}{2\pi \times 0.3275 \times 0.07 \times 3.53}}$$

$$\dot{Q} = \frac{379}{1.38 + 1.844 + 1.96}$$

$$\dot{Q} = 73.11W$$

Table4. 2 Designed values of heat transfer rate with a given outer radius

Outer radius (R2) (cm)	29.5	30	30.5	31	31.5	32	32.5	32.75
Heat transfer rate, Q (W)	99.2	93.95	89.01	84.86	81	77.58	74.48	73.11

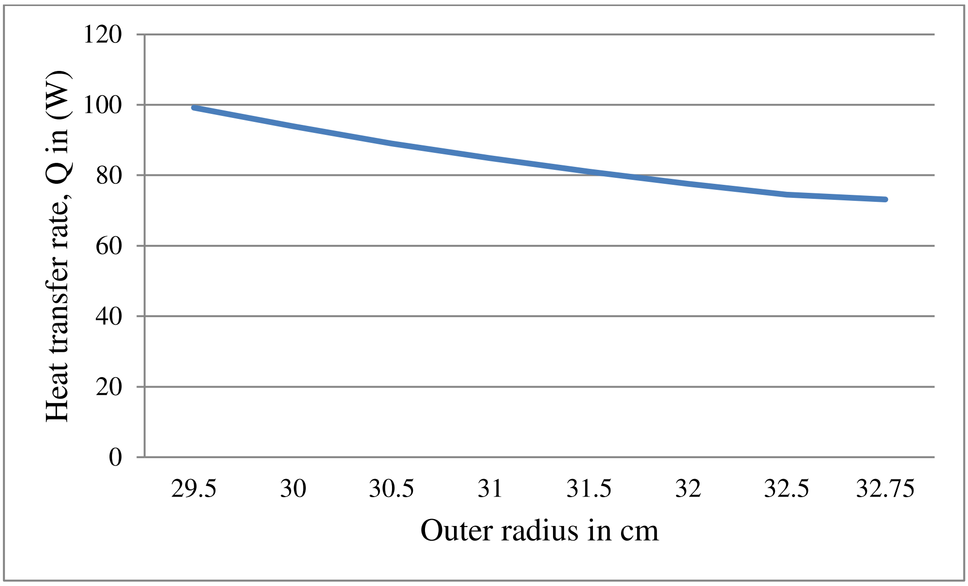


Figure4. 2 Heat transfer rate Vs outer radius

The above table and graph show that the result of heat transfer rate by varying the outer radius of combustion chamber insulation. As shown from the above figure the heat transfer rate decreases as the outer radius of insulation increases. Then among the above result take the outer radius of the combustion chamber which is 32.75cm. Then from the above result determine the thickness of combustion chamber insulation. So the thickness of insulation is simply the difference of outer diameter and internal diameter which is t= 6.5cm.

4.1.12.3 Convective heat transfer coefficient between pan and lid cover

Heat transfer across the baking lid cover by free convection to the environment. The heat transfer coefficient from the baking pan surface to the lid cover can be determined by equation below.

$$h_{1lc} = \frac{KN_u}{L_{pl}} \tag{4.32}$$

Where

h_{lc} – 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

For horizontal plate and uniform surface temperature of the baking pan, Nusselt number is given as:

$$N_u = 2 + 0.6{P_r}^{0.33}{G_r}^{0.25} \tag{4.33}$$

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

When

For

$$10^5 < R_a < 2 \times 10^7 \ldots\ldots\ldots\ldots\ldots N_u = 0.54(R_a)^{0.25} \tag{4.34}$$

For

$$2 \times 10^7 < R_a < 3 \times 10^{10} \ldots\ldots\ldots\ldots\ldots N_u = 0.14(R_a)^{1/3} \tag{4.35}$$

$$R_a = G_r \times P_r \tag{4.36}$$

$$R_a = \frac{g \times \beta \times \Delta T \times {L_{pl}}^3}{\gamma^2} \times P_r \tag{4.37}$$

Where

R_a-Rayleigh number

G_r-Grashoffs number

P_r- Pradlt number

The air properties will be considered at mean temperature between them

$$\Delta T = \frac{T_{lc} + T_p}{2} \tag{4.38}$$

$$\Delta T = \frac{60 + 190}{2}$$

$$\Delta T = 125$$

Where

ΔT – Mean temperature

T_{lc}- Temperature of lid cover

T_p- Temperature of baking pan

$$R_a = \frac{9.81 \times 0.0000858 \times 125 \times 0.1^3}{(2.5 \times 10^{-7})^2} \times 1.4611$$

$$R_a = 2.361 \times 10^9$$

From the above result of Rayleigh number the recommended correlation for the upper heated surface of baking pan is given as:

For $2 \times 10^7 < R_a < 3 \times 10^{10}$ ....$N_u = 0.14(R_a)^{1/3}$, then

$$N_u = 0.14(2 \times 10^9)^{1/3}$$

$$N_u = 186.42$$

There for the convectional heat transfer coefficient between baking pan Mitad and lid cover becomes:

$$h_{1lc} = \frac{KN_u}{L_{pl}}$$

$$h_{1lc} = \frac{0.68 \times 186.42}{0.1}$$

$$h_{1lc} = 1267.65\, W/m^2K$$

4.1.12.4 Convective Heat Transfer Coefficient from Lid Cover to the Ambient

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

$$h_{2lc} = \frac{KN_u}{L_{pl}} \tag{4.39}$$

$$R_a = G_r \times P_r$$

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:

$$\beta = \frac{1}{T_K} \tag{4.40}$$

Consider property of air

$$\Delta T = T_{lc} - T_a$$

$$\Delta T = 60 - 21$$

$$\Delta T = 39°\text{C}$$

$$T_k = 273 + 40 = 312k$$

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

$$R_a = \frac{g \times \beta \times \Delta T \times {L_{pl}}^3}{\gamma^2} \times P_r$$

$$R_a = \frac{9.81 \times 0.00319 \times 40 \times 0.6^3}{(1.701 \times 10^{-5})^2} \times 0.7255$$

$$R_a = 6.79 \times 10^8$$

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

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

$$N_u = 0.14(6.79 \times 10^8)^{1/3}$$

$$N_u = 123.1$$

Therefore the convectional heat transfer coefficients from lid cover to ambient is determined as follow:

$$h_{2lc} = \frac{KN_u}{L_{pl}}$$

From [61], the thermal conductivity of lid cover at a temperature of 60^{o}c which is 0.57

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

4.1.12.5 Radiative Heat Transfer Coefficient from the Baking Pan Surface to the Lid Cover

The determination of radiative heat transfer coefficient from the baking pan surface to lid cover by considering the same radiating, pan surface area and a unite value of geometric factor. Then the overall coefficient of radiation heat transfer is equal to the summation of series emissivity of pan and lid cover. Then radiative heat transfer coefficient from the baking pan surface to lid cover could be determined as follow:

$$h_{1r} = \zeta \varepsilon_{eff} \left(\frac{(T_P + 273)^4}{T_P - T_{lc}} - \frac{(T_{lc} + 273)^4}{T_p - T_{lc}} \right) \quad (4.41)$$

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

$$\varepsilon_{eff} = \left[\frac{1}{\epsilon_P} + \frac{1}{\epsilon_{LC-1}} \right]^{-1} = 0.11 \quad (4.42)$$

$$h_{1r} = \zeta \varepsilon_{eff} \left(\frac{(T_P + 273)^4}{T_P - T_{lc}} - \frac{(T_{lc} + 273)^4}{T_p - T_{lc}} \right)$$

$$h_{1r} = 5.67 \times 10^{-8} \times 0.11 \left(\frac{(190 + 273)^4}{190 - 60} - \frac{(60 + 273)^4}{190 - 60} \right)$$

$$h_{1r} = 1.62\,9W/m^2k$$

4.1.12.6 Radiative heat transfer coefficient from lid cover to ambient

The surrounding temperature or sky temperature is given by:

$$T_{sky} = T_a - 6 = 20 \quad (4.43)$$

$$T_{sky} = 26$$

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

$$h_{2r} = \zeta \varepsilon_{eff} \left(\frac{(T_{lc} + 273)^4}{T_{lc} - T_{sky}} - \frac{\left(T_{sky} + 273\right)^4}{T_{lc} - T_a} \right)$$

$$h_{2r} = 5.67 \times 10^{-8} \times 0.11 \left(\frac{(60+273)^4}{60-26} - \frac{(26+273)^4}{60-21} \right)$$

$$h_{2r} = 2.314\, W/m^2k$$

4.1.12.7 Rate of Heat Transfer from Baking Pan (Mitad) to the Ambient Per Unit Area

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

$$U_t = \left[\frac{1}{h_1} + \frac{1}{h_2}\right]^{-1} \tag{4.44}$$

Where, h_1 and h_2 are the heat transfer due to convection as well as the equivalent radiation heat transfer from pan surface, which is given by:-

$$h_1 = h_{1lc} + h_{1r} \tag{4.45}$$

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

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

$$h_2 = h_{2lc} + h_{2r} \tag{4.46}$$

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

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

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

$$U_t = \left[\frac{1}{h_1} + \frac{1}{h_2}\right]^{-1} \tag{4.47}$$

$$U_t = \left[\frac{1}{1268.7} + \frac{1}{35.054}\right]^{-1}$$

$$U_t = 34.01\, W/m^2k$$

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

$$Q_t = U_t(T_P - T_{li}) \quad (4.48)$$

$$Q_t = 34.01(190 - 60)$$

$$Q_t = 4421.3\, w/m^2$$

The amount of heat waste from baking pan to ambient could be energy absorbed by the output and also the amount of energy waste during the time of heating up of Mitad as well as subsequent injera baking process or cycle could be determined as follow:

$$Q_t = U_t(T_P - T_{li}) \times A \quad (4.49)$$

$$Q_t = 4421.3\, w/m^2 \times \frac{\pi d^2}{4}$$

Where d is the diameter of baking Mitad which is 60mm=0.06m

$$Q_t = 4421.3\, w/m^2 \times \frac{\pi 0.06^2}{4} = 12.49W$$

Table4. 3 The overall size and dimension of the existing and newly developed biogas injera baking stove

No.	Parameter	Existing biogas injera baking stove	New biogas injera baking stove
1.	Burner construction material	Mild steel	Miled steel
2.	Burner type	Spiral	Tubular burner
3.	Diameter of burner	10mm	10mm
4.	Insulation type	Cement	A mixture of gypsum and brick
5.	Thickness of insulation	3cm	6.5cm
6.	Diameter of Throat	20mm	20mm
7.	Length of throat	20cm	30cm
8.	Diameter of Injector	5mm	5mm
9.	Over all stove height	71cm	82.5cm
10.	Flam height	1cm	3.3cm
11.	Diameter of flam port	1.5mm	3mm
12.	The gap b/n each bar(burner spacing)	Not proper 7, 6.5, 12	3.4cm
13	Number of bar burner	3	9
14.	Number of secondary air intake holes	12	5
15.	Size of secondary air intake hole	(1.5× 11)cm	(3×17)cm
16.	Number of primary air intake holes	-	6
17.	Diameter of primary air intake hole	-	3mm
18.	Number of pan support	6	4
19.	Height of pan support	1cm	1cm
20.	Diameter of baking pan	60cm	60cm

21.	Number of flam port	558	623
22.	The gap b/n each flam port	2mm	5mm
23.	The distance b/n bottom combustion to burner	2cm	2.5cm
24.	Over all combustion chamber height	6.5cm	8cm

Table4.4 show the overall size and dimension of the existing and newly developed biogas injera baking stove. As shown from the above table, the overall dimension of existing biogas injera baking stove dimension was recorded by direct measuring the body of stove. However, the overall dimension and part size of newly developed biogas injera baking stove was obtained from the analytical design as discussed on chapter four.

4.2 Fabrication

The prototype of newly developed biogas injera baking stove was fabricated in Debre Birhan University. The university is located approximately 130Km from Addis Abeba. The biogas stove for injera baking purpose was developed based on the parameters and dimensions obtained from the analytical design presented in the next chapter of this study. During the fabrication process of the stove, the main parameters that were taken in to account include the throat diameter, injector or orifice diameter, mixing tube length, number of burner port and their diameter, flame height, insulation material, overall stove height, number of secondary air intake holes and their overall dimension, insulation thickness, internal and outer diameter of combustion chamber. Now in this section the overall fabrication process including available materials and machining tools for fabrication of newly developed biogas injera baking stove is discussed briefly and summarized by in table form.

4.2.1Available materials for fabrication

During fabrication process a number of available materials for construction of newly developed biogas injera baking stove were needed. As shown in the table 3.4 available materials for construction of newly developed biogas injera baking stove were discussed and summarized in table form. The materials such as flat iron and sheet metal is used for mold preparation and for the construction of body of the combustion chamber, angle iron for bottom combustion chamber support, RHS (Rectangular hollow tube) is used for leg support of the stove, CHS (Circular hollow tube) is used for construction of burner, the mixture of gypsum and brick is used for insulation of the combustion chamber.

Table4. 5 Available material for construction of newly developed injera baking stove

No.	Available materials for construction of newly developed injera baking stove	
1.	Flat iron: for mold preparation	
2.	Sheet metal: for bottom and side combustion chamber	
3.	RHS(Rectangular hollow steel): for lege	
4.	CHS(Circular hollow steel): for burner	
5.	Gypsum and brick: for insulation	 

4.2.2Machining tool

As shown in table 4.2 below a number of machining tools were used for manufacturing of the biogas stove. Fabrication of the newly developed biogas injera baking stove was done in Debre Birhan university mechanical engineering manufacturing lab. During machining process roller is used for rolling the flat iron and sheet metal, grinder is used for cutting process throughout the manufacturing process, bender also used for bending the metal at any angle, hammer at any stage of welding process is taken, electrode is also taken through welding process, drilling machine and 3mm drill bit is used for burner flame port, sheet metal cutting machine and pipe bender also taken for manufacturing process.

Table4. 6 Machining Tools

No.	Machining tool	
1.	Roller	
2.	Grinder	
3.	Bender	

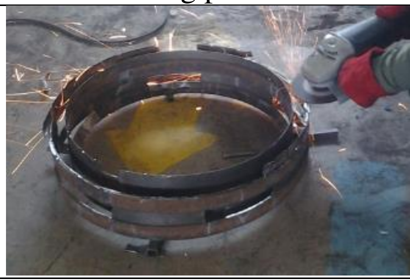
4..	Hamer	
5.	Electrode	
6.	Drilling machine	
7.	Sheet metal cutting machine	
8.	Pipe bender	

9.	Arc welding	

4.2.3 Steps of fabrication process

By using the machining equipment and stove construction materials that are discussed in the previous section in order to fabricate the biogas stove. Now in this section the overall fabrication process is discussed briefly and summarized in table form. As shown in table 4.3 the overall steps of fabrication process is discussed in table form. The fabrication process is started from construction of combustion chamber die for mold by using sheet metal and flat iron. In this stage the machining processes that are done on rolling, cutting, grinding and welding. Step two is brick milling process during this step the fire brick is milled by hammer. After milling the brick by using the mixture of gypsum and brick prepare the mold for the combustion chamber. After mold preparation by using RHS and CHS construct the biogas burner. The burner have 9 number of CHS connected in parallel by two RHS and it have two number of injector connected at the right and the left side of the burner. During construction of a burner cutting, welding, drilling and grinding were the main machining processes. Step five is the construction of leg support by using RHS, Angle iron and flat iron. During this process cutting, grinding, welding and drilling were the main manufacturing processes. Step six is the assembling process. Step seven is preparing the baking pan support by molding process at the top of the combustion chamber. There are four number of baking pan supports. The final step was painting the stove body.

Table4. 7 Steps of fabrication process

Steps	Machining process	Manufacturing process
1. Construct die for mold by using sheet metal and flat iron	Rolling, cutting, grinding & welding	
2. Brick milling process	Milling the brick by hammer	
3. Mold preparation	A mixture of gypsum and brick	
4. Construction of burner using RHS and CHS	Cutting, welding, drilling, and grinding	
5. Construction of leg support by using RHS, angle iron and flat iron	Cutting, grinding, welding and drilling	 

6. Assembling	Welding	
7. Baking pan support	molding	
8. Over all stove body	Painting	

Chapter 5

5. Experimental test Result and Discussion

In this section, the experimental test result of the existing and newly developed biogas injera baking stove is discussed and summarized in table and graphical form. From the experimental test result, the newly developed biogas injera baking stove showed a remarkable performance as compared with the performance of existing biogas injera baking stove. During experimental test temperature, cooking time, Amount of gas consumption, efficiency, Amount of energy needed and quality of injera were the main parameters for evaluating the performance of existing and newly developed biogas injera baking stove. In addition, the economic analysis result of newly developed biogas injera baking stove with regards initial investment, net cash flow, payback period and net present value also discussed on the following sections.

5.1 Performance evaluation parameters and its result during baking process

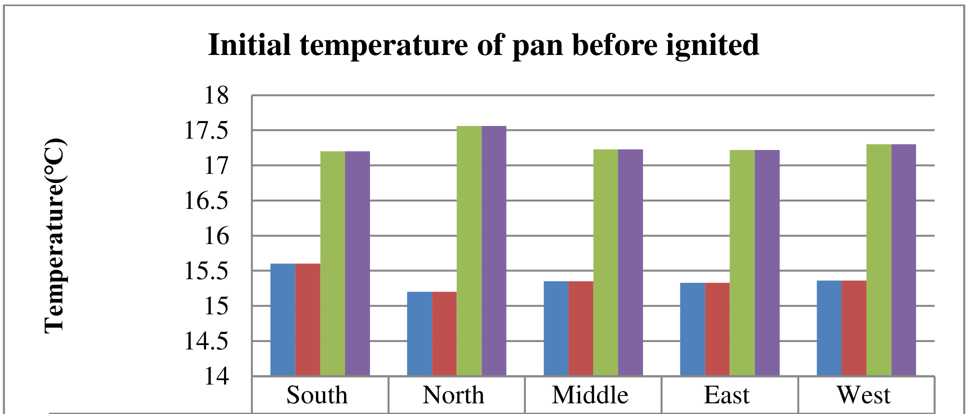
In this study, Temperature distribution, Cooking time, Amount of biogas consumption, Quality of injera, amount of energy needed and efficiency of the stove are the main parameters that Evaluate the performance of biogas injera baking stove.

5.1.1 Temperature distribution

By using an infrared thermo meter the temperature distribution through the baking pan of the existing and new 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 ignited the 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 by three different measuring instruments such as PT-100 Thermocouple connected with digital multimeter, K-Type thermocouple connected with digital multimeter and Bimetallic thermometer.

I. Temperature

A. Initial temperature of pan before ignited



	South	North	Middle	East	West
Test 1 Existing	15.6	15.2	15.35	15.33	15.36
Test 1 New	15.6	15.2	15.35	15.33	15.36
Test 2 Existing	17.2	17.56	17.23	17.22	17.3
Test 2 New	17.2	17.56	17.23	17.22	17.3

Figure5. 1 Initial temperature of pan before ignited

Figure 5.1 shows the initial temperature of pan before ignited. As shown from the above figure the initial temperature of injera baking pan before the fire ignited on the burner was measured by an infrared thermometer and the test was conducted on two phases and also the temperature of baking pan was measured in five direction of pan such as south, north, middle, east and west direction of the baking pan. For experimental test only one baking pan is taken for existing and newly developed biogas injera baking stove. So the result obtained from the experimental test, on the first and the second round of test the temperature of baking pan on newly developed and existing biogas injera baking stove showed the same result but the result on the south, north, middle, east and west direction of the baking pan were slightly different from each other. This value was depending on the weather condition.

B. Baking temperature of pan before baking injera

The heating temperature of baking pan before the dough was powered on the pan was measured at the five direction of the baking pan such as at south, north, east, middle and west of the baking pan. In this experiment two round of test have been conducted for existing and newly developed biogas injera baking stove. The temperature was measured by an infrared thermometer.

- ❖ Baking temperature of pan before baking injera (Round one)

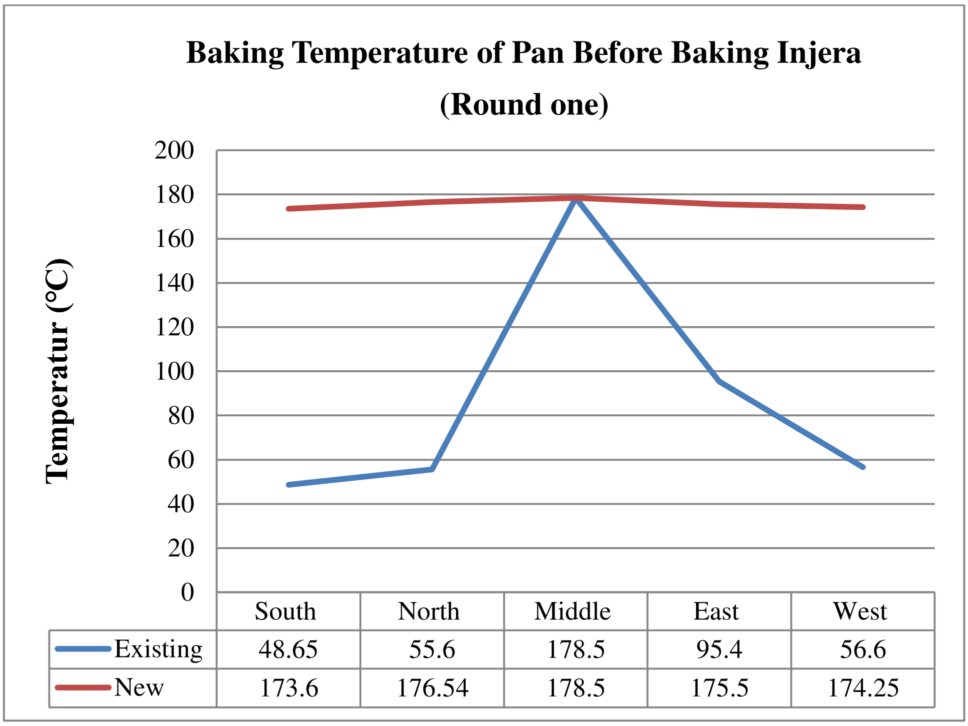


Figure5. 2 Baking temperature of pan before baking injera on the first round

Figure 5.2 show baking temperature of pan before baking injera. As shown from the above figure on the first round of experimental test, the heating temperature of pan was measured and recorded at five direction of the baking pan such as in the south, north, middle and east and west direction. From experimental test result the existing biogas injera baking stove showed un equal heat distribution on the surface of the baking pan. However, the baking temperature of pan before baking injera on newly developed biogas injera baking stove showed a remarkable performance than the existing one.

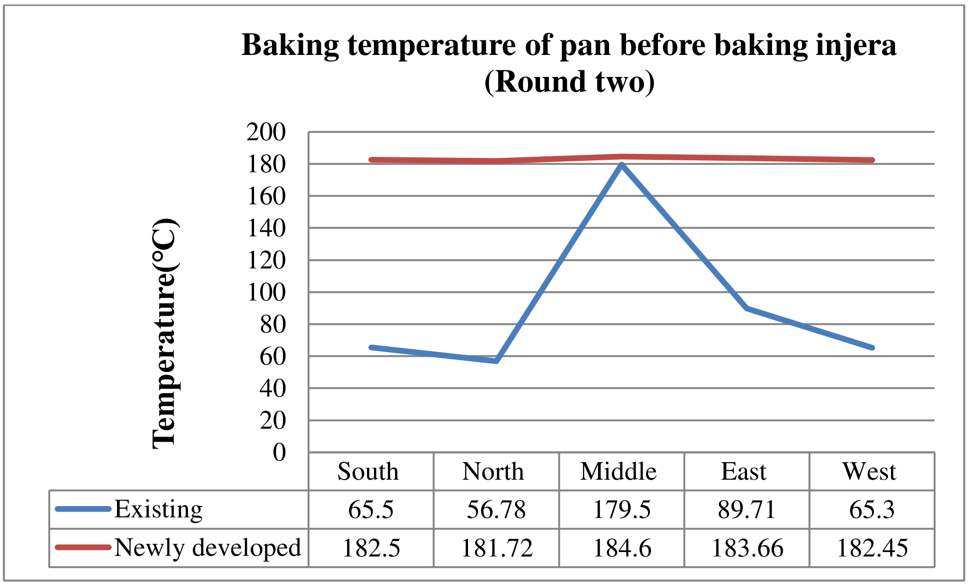


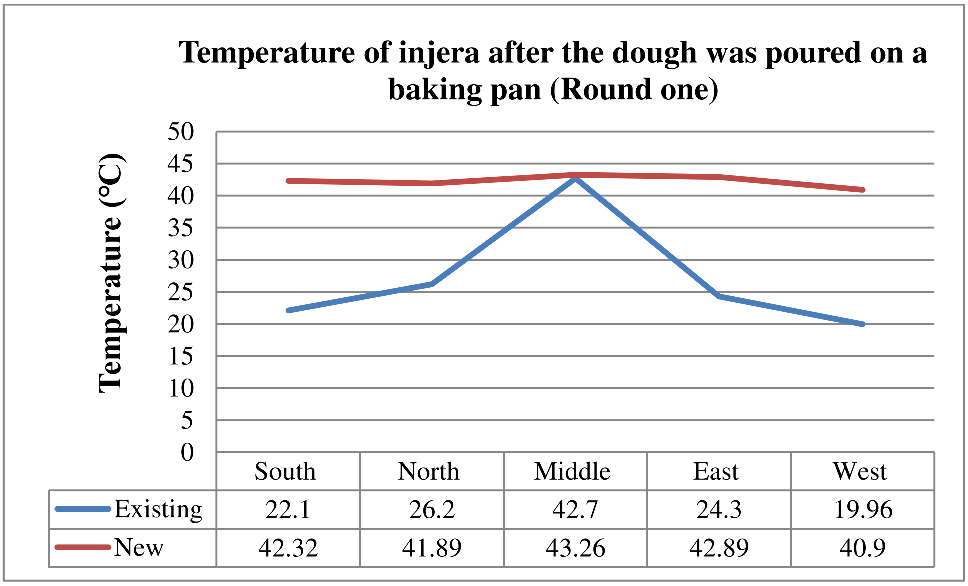
Figure5. 3 Baking temperature of pan before baking injera on the second round

Figure 5.3 shows the baking temperature of pan before baking an injera on the second round. As shown from the above table the heating temperature of baking pan before the dough was powered on the pan also measured at the five direction of the baking pan such as at south, north, east, middle and west of the baking pan. The experimental test result showed, the temperature distribution through the baking pan was not uniform on the existing biogas injera baking stove. However the newly developed biogas injera baking stove also showed a better performance than the existing one.

C. Temperature of injera during baking

The temperature of injera was also measured at five direction of the baking pan such as at the south, north, middle, east, and west of the baking pan. The experiment was conducted on the two round of existing and newly developed biogas injera baking stoves.

- ❖ Temperature of injera after the dough was poured on a baking pan (Round one)



	South	North	Middle	East	West
Existing	22.1	26.2	42.7	24.3	19.96
New	42.32	41.89	43.26	42.89	40.9

Figure5. 4 Temperature of injera after the dough was poured on the baking a pan (round one)

Figure 5.4 shows Temperature of injera after the dough was poured on the baking pan. As shown from the above figure, the temperature of injera baked by existing and newly developed biogas injera baking stove was also measured by infrared thermometer. The experimental test result showed the temperature of injera at the middle of baking pan was higher than the remaining direction of injera on the existing biogas injera baking stove. However, the result obtained from newly developed biogas injera baking stove, the temperature distribution through the baking pan of newly developed biogas injera baking stove was uniform for this reason the temperature of injera after the dough was poured on the baking pan was good.

- Temperature of injera after the dough was poured on a baking pan (Round Two)

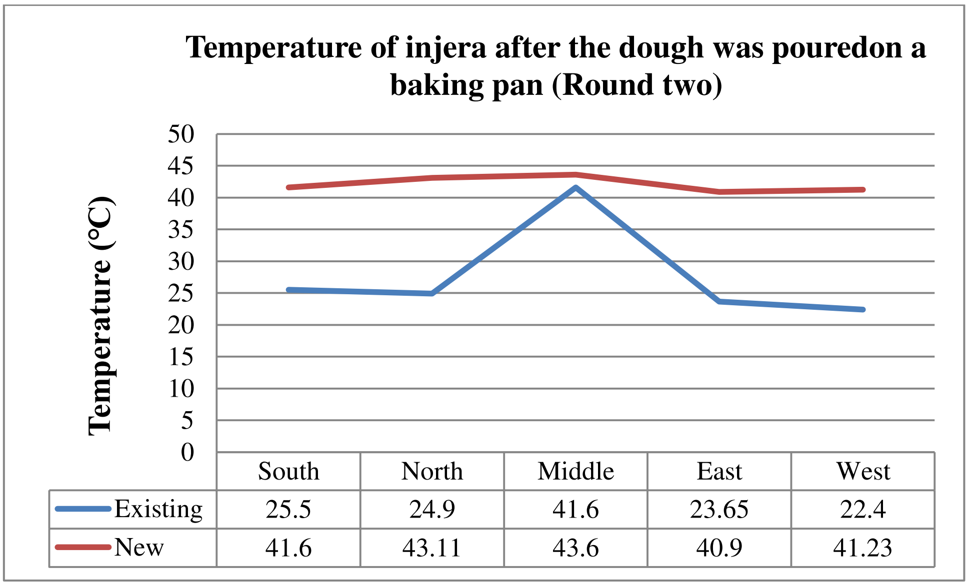
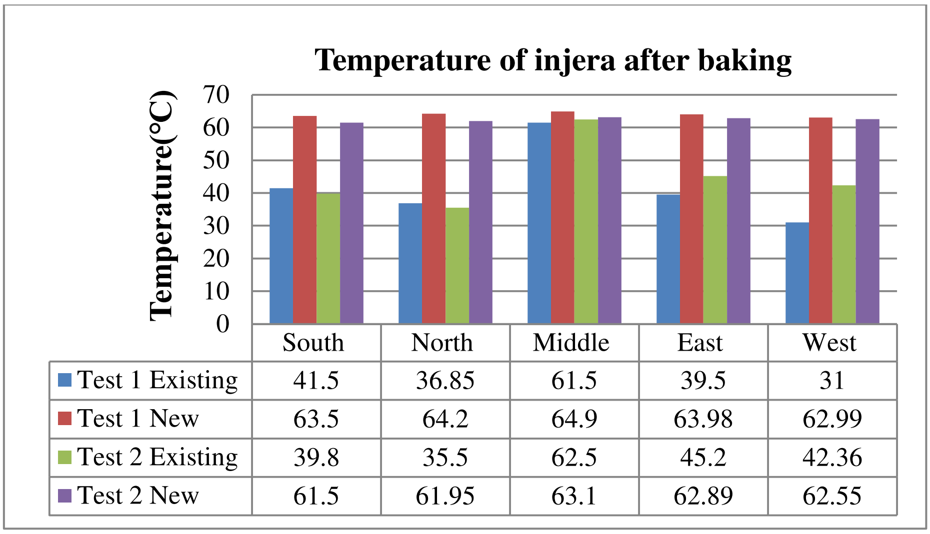


Figure5. 5 Temperature of injera after the dough was poured on a baking pan(round two)

Figure 5.5 show the experimental test result of temperature of injera after the dough was poured on a baking pan. As shown the above figure, on the second round of experimental test the temperature of injera after the dough was poured on the a baking pan was measured at the five direction of the baking pan such as at the south, north, middle, east and west direction of the baking pan. During experimental test the newly developed biogas injera baking stove showed a remarkable performance than the existing biogas injera baking stove.

D. Temperature of injera after baking

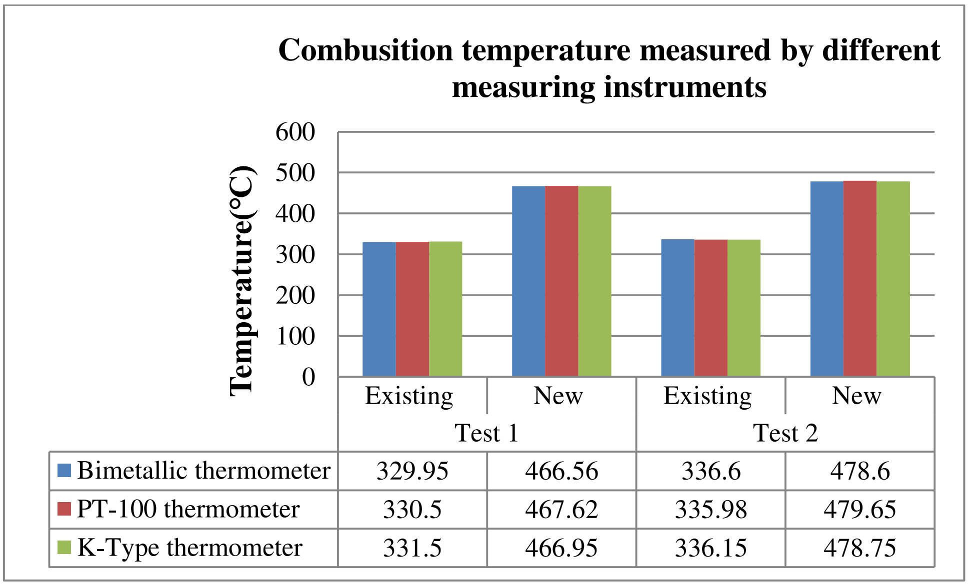


	South	North	Middle	East	West
Test 1 Existing	41.5	36.85	61.5	39.5	31
Test 1 New	63.5	64.2	64.9	63.98	62.99
Test 2 Existing	39.8	35.5	62.5	45.2	42.36
Test 2 New	61.5	61.95	63.1	62.89	62.55

Figure5. 6 Temperature of injera after baking

Figure 5.6 shows the temperature of injera after baking. As shown from the above figure, the temperature of injera on the two round of test was measured on the five directions such as south, north, middle, east and west. The temperature of injera baked by the existing biogas injera baking stove was higher at the middle but on the remaining direction the temperature of injera was lower. And also the temperature of injera baked by the newly developed biogas injera baking stove was almost equal through the whole direction and also the quality of injera was good compared with existing one.

E. Combustion temperature measured by different measuring instruments

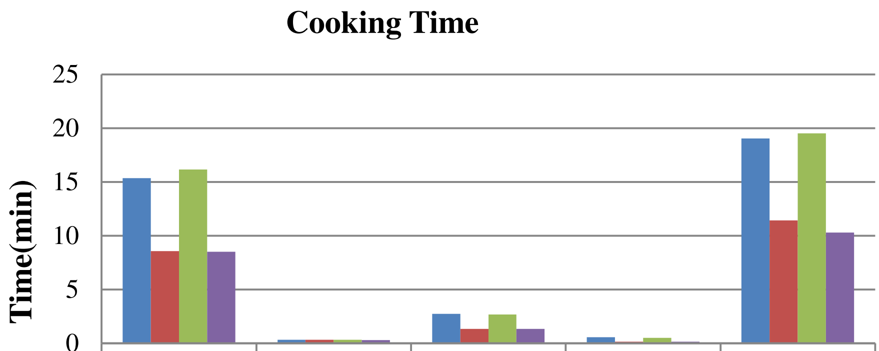


	Test 1		Test 2	
	Existing	New	Existing	New
Bimetallic thermometer	329.95	466.56	336.6	478.6
PT-100 thermometer	330.5	467.62	335.98	479.65
K-Type thermometer	331.5	466.95	336.15	478.75

Figure5. 7 Combustion temperature measured by different measuring instruments

Figure 5.7 shows the combustion temperature measured by different measuring instruments. As shown from the above figure, the combustion temperature of existing and newly developed biogas injera baking stove was measured by bimetallic thermometer, PT-100 thermometer and K-Types thermocouple connected with digital multimeter. The results obtained from these three devices were almost similar. The combustion temperature of newly developed biogas stove was higher than the existing one.

II. Cooking time



	Heating time before pouring the first injera	The time first pouring of dough tooks place	The time the baked injera was removed off	The time to heat the metad before next injera was going to be baked	Total cooking time
Test 1 Existing	15.367	0.333	2.75	0.5833	19.033
Test 1 New	8.583	0.333	1.333	0.1667	11.42
Test 2 Existing	16.15	0.333	2.667	0.5	19.53
Test 2 New	8.5	0.3	1.333	0.1667	10.3

Figure5. 8 Cooking time

Figure 5.8 shows the overall cooking time through the baking process. As shown from the above figure the cooking time that is starting from the fire ignites to the burner up to the time that the end of the first baking process was recorded. These cooking times such as heating time before pouring the first injera, the time first pouring of dough tooks place, the time the baked injera was removed off and the time to heat the Mitad before next injera was going to be baked. Finally, record the total cooking time through the process. In this experiment 2 tests have been conducted. During experimental test the existing biogas injera baking stove takes long period of time through each process compared with newly developed biogas injera baking stove. At the first round test the total cooking time of existing biogas injera baking stove was 19.033min and the newly developed biogas injera baking stove was 11.42min. at the second round of baking process the total cooking time of existing and newly developed biogas injera baking stove was 19.53min and 10.3min respectively.

III. Amount of biogas consumption (l)

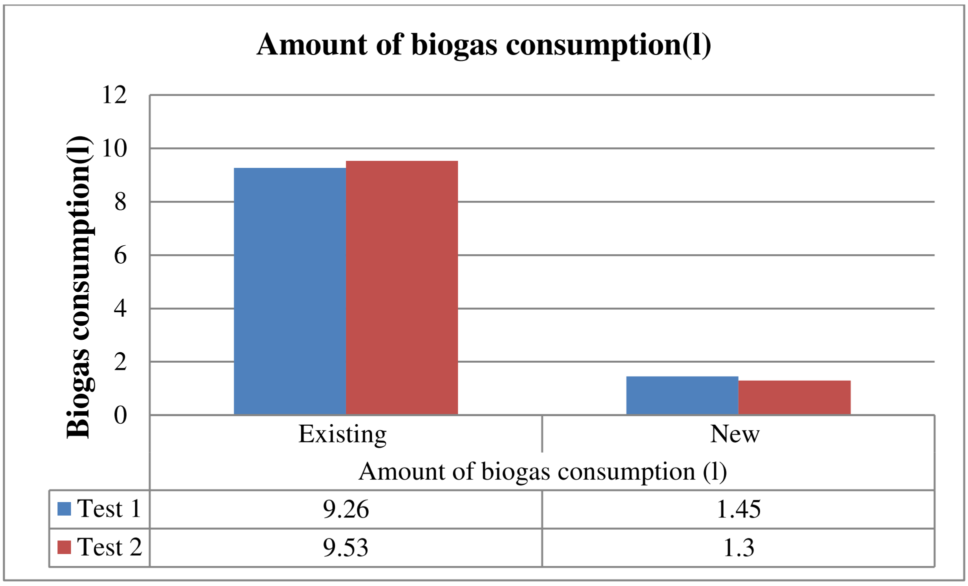


Figure5. 9 Amount of biogas consumption

Figure 5.9 shows the amount of biogas consumption. As shown from the above figure the amount of biogas consumption in litter was measured by using gas flow meter. From the experimental test result the existing biogas injera baking stove consumes higher amount of biogas through the two round of testing process than the newly developed biogas injera baking stove.

IV. Cooking time and Amount of biogas consumption comparison

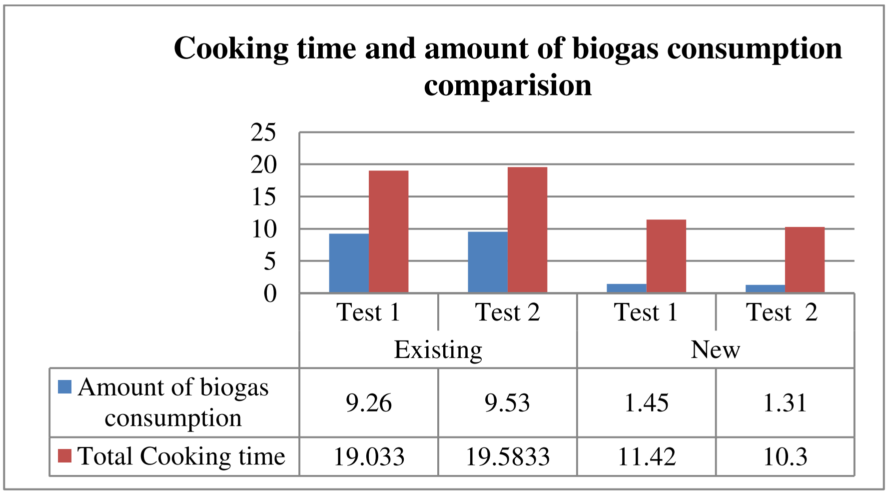


Figure5. 10 Cooking time and Amount of biogas consumption comparison

Figure 5.10 shows the amount of biogas consumption and cooking time comparison. As shown from the above figure the amount of biogas consumption and baking time were the main parameters to test the existing and newly developed biogas injera baking stoves. So the experimental test result shows, through the whole testing process the total cooking time of the existing biogas injera baking stove takes a long time for this reason the amount of biogas consumption was higher. However, baking of injera by newly developed biogas injera baking stove take a short cooking time period and it consumes less biogas. Generally, the higher the cooking time the more consumes the biogas and also the shorter the baking time, less consumption of biogas.

Quality of Injera

Figure5. 11Injera baked by existing biogas injera baking stove

Figure5. 12 Injera baked by newly developed biogas injera baking stove

5.2 Cost Analysis and Economic Analysis of Newly Developed Biogas Stove

The initial investment for manufacturing the newly developed biogas injera baking stove is summarized in table below.

Table5. 1 Material cost of newly developed biogas injera baking stove

	Material cost				
No.	Item	Unit price	Unit	quantity	Remark
1.	Sheet metal	420	Pcs	1	0.5mm thickness
2.	Angel iron	300	Pcs	1	6m
3.	Flat iron	410	Pcs	1	6m
4.	RHS	280	Pcs	1	25× 25 ×0.5
5.	CHS	160	Pcs	1	Ø10mm
6.	Electrode	220	Packet	1	Ø2.5 ×300
7.	Grinder disc	70	Pcs	1	
8.	Gypsum	120	25kg	1	
9.	Fire Brick	150		15	
10.	Painting	160	Spray	2	
10.	Labor cost	500			
Total selling cost biogas stove = 2950					

5.3 Economic Analysis

In this section, the economic analysis such as the net cash flow rate, the initial investment required, saving an income gained during the utilization of biogas, the net present value and payback period is computed. The estimated cash outflows and cash inflows are the preferred inputs because, ultimately the value of all financial investments is determined by the value of cash flows paid and received. Cash out flows such as initial investment, maintenance and repair, increased operating costs and overhauling of equipment, etc.… cash inflows such as increased cash received from customers, reduced cash out flows related to operating costs etc.…. The determination of net present value is necessary because the given project is acceptable when net present value is zero or positive. If the net present value is negative the given project is not acceptable.

Before going to determining the NPV it is required to determine the overall cash flow of the project

Cash out flow

- The initial investments needed for utilization of biogas injera baking application such as construction of biogas digester and installation of the system for biogas stove should be determined. The total cost of 8m^3 biogas digester is 10000ETB. The cost of newly developed biogas injera baking stove is 2950ETB. The initial expense will be 12,950ETB.
- Payment for the person taking care of the digester will be: $20 birr/day \times 365 days = 7300$ETB.
- Running cost such as expense for water will be determined based on the quantity of animal dung per day and the number of cow. During experiment the biogas digester size is 8m^3 and the households have 5 numbers of cows then per day 60kg of animal dung are collected from cows. During biogas preparation process for 60kg of animal dung they take 60litter of water. Then, the expense for 60 litter of water is used and its cost is 5 birr the expense per annum will be 5 birr/day ×365 day= 1825ETB.

Cash in flow

Coming to saving made by $8m^3$ biogas digester, the expenses for fire wood, the expense for cleaning the cow dung was considered and also the additional income from selling the digester byproduct as a fertilizer can also considered.

- Saving of wood expenses, from house hold view and by direct interview of the farmers that was stayed on keyte woreda, then for the first round of baking process they baked 32-37 number of injera and also the price of wood consumed is 180 birr, for 8 numbers of families. So annually it becomes 180birr/day × 120days =21,600ETB.
- Saving of cow dung cleaning cost will be 10birr/day×365day= 3650ETB.
- Savings from selling the digester byproduct as a fertilizer annually 20,000ETB.

Table5. 2 Saving and expense in utilization of biogas for injera baking application

No.	Activities	Types of cash flow	Expense	Saving
1.	Digester	Initial (cash outflow)	10,000	
2.	Biogas stove	Initial (cash outflow)	2,950	
3.	Fire wood purchase	Cash inflow		21,600
4.	Cow dung cleaning	Cash inflow		3,650
5.	Digester care taker	Cash out flow	7,300	
6.	Selling the digester byproduct as a fertilizer	Cash inflow		20,000
7.	Water for mixing and cleaning	Cash outflow	1,825	
Total expense and savings excluding initial investments			22075ETB	45250ETB
Net saving (Net annual cash flow) from using biogas per annum			23175ETB	

From the above table the net annual cash flow in utilization of biogas for injera baking is 23,175ETB.

i.e $Net\ annual\ cash\ flow = Annual\ cash\ in\ flow\ - Annual\ cash\ out\ flow$

$$Net\ annual\ cash\ flow = 45250ETB\ - 22075ETB$$

$$Net\ annual\ cash\ flow = 23175ETB$$

Payback period

The payback period of biogas utilization is determined as follow:

The cash payback period identifies the time period required to recover the cost of the capital investment (initial investment) for biogas digester as well as biogas stove from the net annual cash inflow produced by the investment.

$$Cash\ payback\ period = Cost\ of\ capital\ investment \div Net\ annual\ cash\ flow$$

$$Cash\ payback\ period = 12950ETB \div 23175ETB$$

$$Cash\ payback\ period = 0.558Yr$$

The payback period is below one year, the shorter the payback period, then the more attractive the project.

Determine the net present value (NPV)

$$NPV = -Initial\ investment + \frac{Net\ annual\ cash\ flow}{(1+R)^Y}$$

$$NPV = -12950 + \frac{23175}{(1+0.15)^1}$$

$$NPV = 7202.173ETB.$$

The net present value of this this project is 7202.173ETB. So this project is acceptable because the higher the positive NPV, the more attractive the investment (project).

Chapter Six

6. Conclusion and Recommendation

6.1 Conclusion

The primary concern of this study was designing, developing and evaluate the performance of biogas stove for injera baking application targeting the assessment of potential in reduction of GHG emission and fire wood dependency. Previously implemented biogas stoves have mainly a problem of uniform heat distribution through the baking pan. So in this study the heat distribution potential of the burner can be maximized by designing and manufacturing a tubular burner, enhancing the combustion process by providing for means of introducing sufficient air for combustion, and further reducing the amount of heat loss from the combustion chamber by insulating with a mixture of gypsum and brick. The experiment was conducted in existing and newly developed biogas injera baking stove. During experimental test cooking time, amount of biogas consumption, temperature, efficiency, amount of energy needed and quality of injera were the main parameters for evaluating the performance of existing and newly developed biogas injera baking stove. The experiment was tested on two rounds. During experimental test the initial temperature of baking pan before the fire ignited, baking temperature of pan before baking an injera, temperature of injera during baking, temperature of injera after baking were measured by infrared thermometer on five direction of the baking pan as well as the injera. From the experimental test result, of newly developed biogas injera baking stove get a uniform temperature throughout the baking pan. However the flam temperature on the existing biogas injera baking stove was not uniform, only at the middle of the baking pan was higher temperature but at the east, west, south and north direction of the baking pan slightly lower heat. The experimental test result showed on the first round of baking process the amount of biogas consumption for baking a single injera by existing and newly developed biogas injera baking stove was 9.26 litters and 1.45 litters respectively. The cooking time for 9.26 litters of biogas consumption takes 19.033minute. However the cooking time for baking a single injera by using newly developed biogas injera baking stove was 1.45 minute Generally, it can be concluded that there is a need to replace the Existing biogas injera baking stove with a newly developed biogas injera baking stove. Because, newly developed biogas injera baking stove having a good performance than the existing one. This study also showed attractive economic feasibility with positive NPV and payback period of less than one year.

6.2 Recommendation

- In this study, validation of result predicted by modeling software is not carried out. So, anyone who is initiate and expert to this studying area will be validating the result predicted by either finite element method or CFD software.

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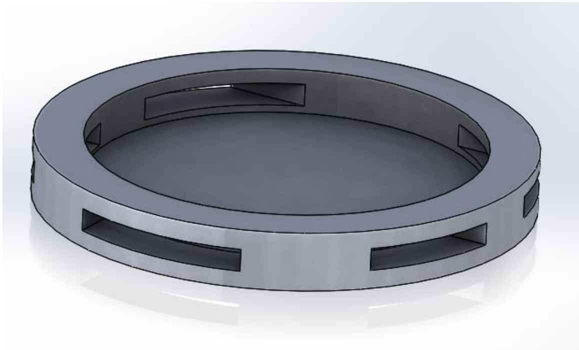
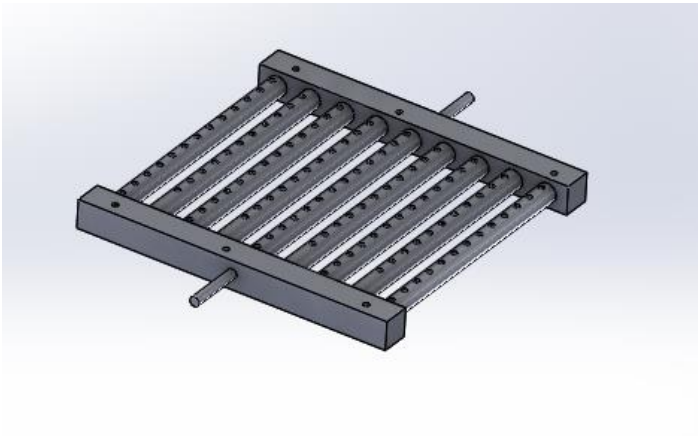
Appendix 1: Assembly drawing of the newly developed biogas injera baking stove. It consists of tubular burner, combustion chamber and leg support

Appendix 2: 3D drawing of Part components of newly developed biogas injera baking stove

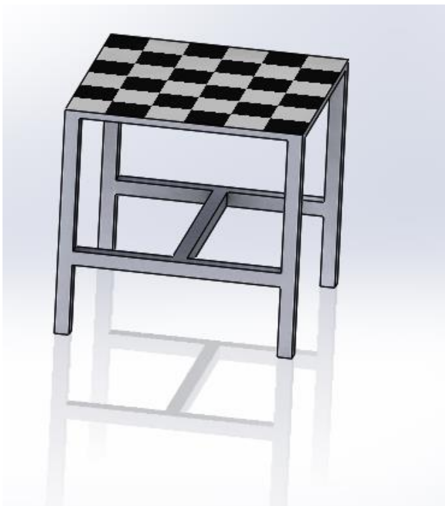
A. Combustion chamber

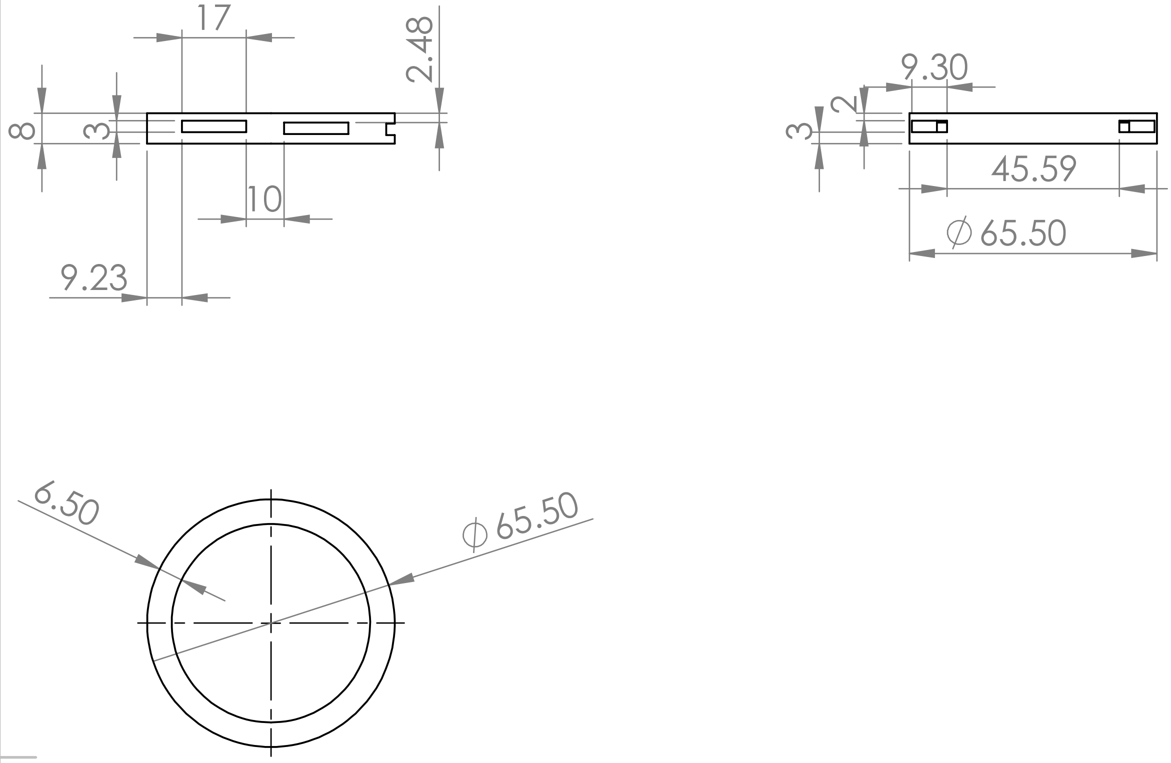


B. Tubular burner



C. Leg support





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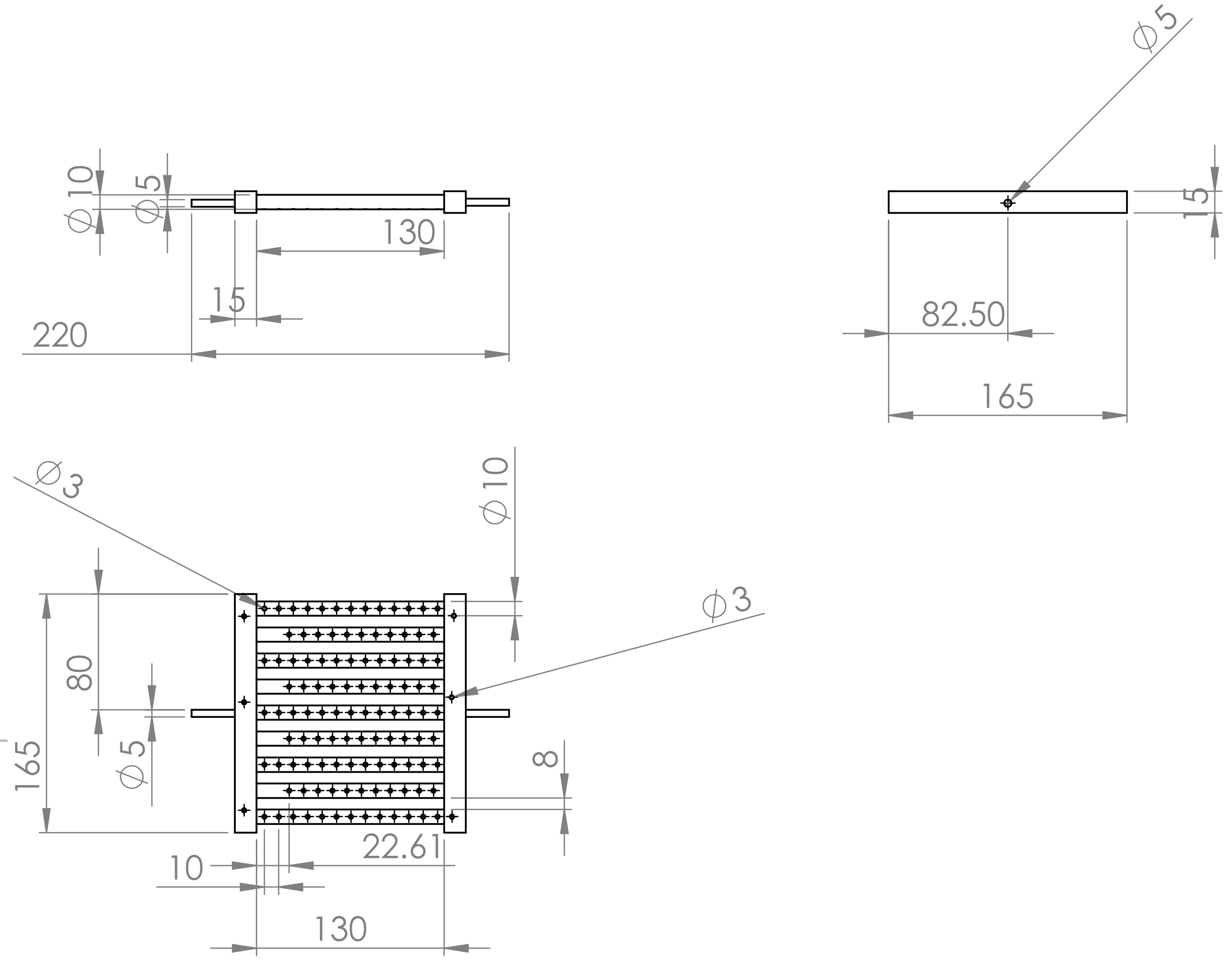

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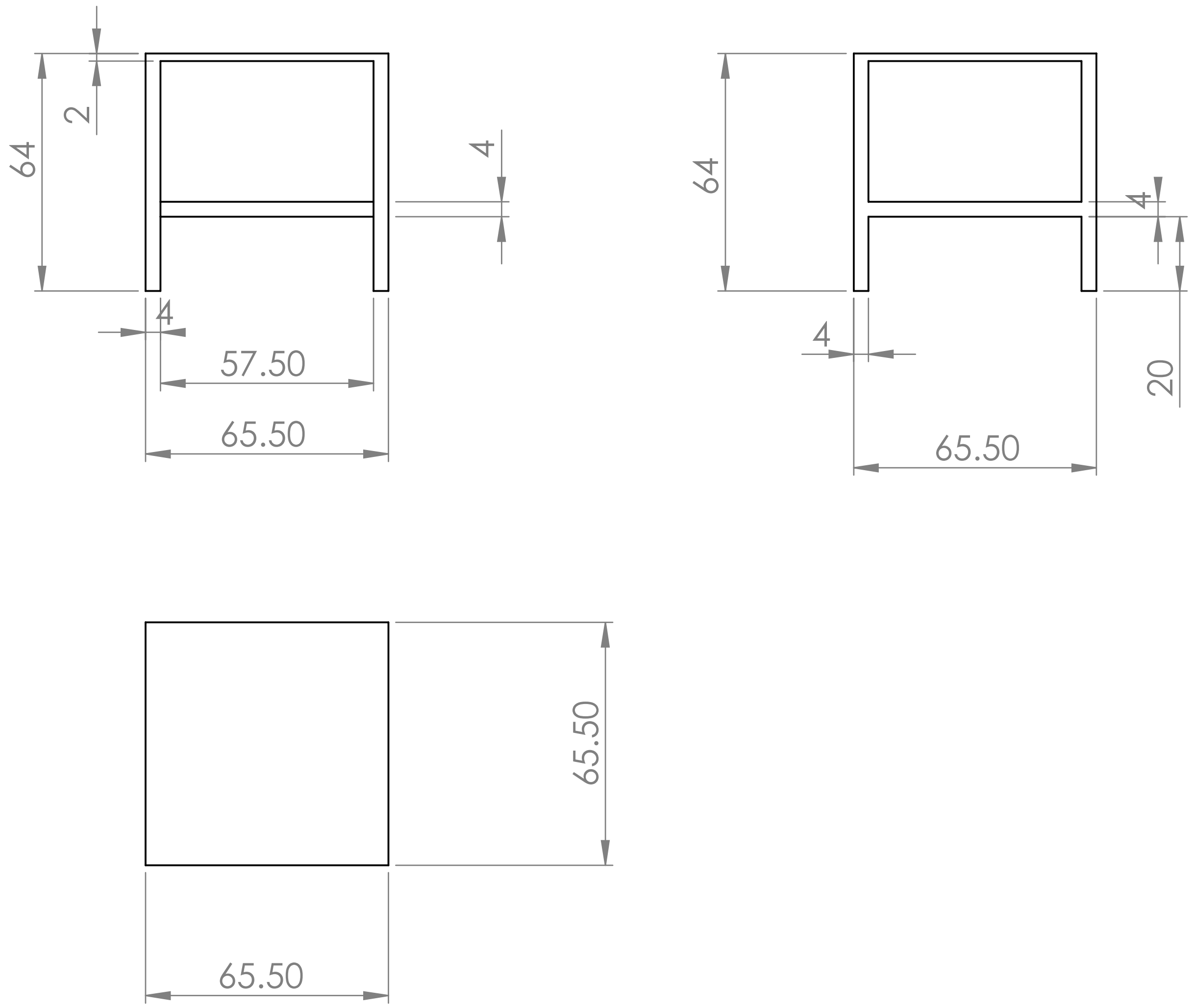

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