JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING

SUSTAINABLE ENERGY ENGINEERIG STREAM

Impact Assessment and Design Modification of Mirt Stove to Mitigate Carbon Emission; in the Case of Jimma Zone

A thesis submitted to the School of Graduate Studies of Jimma University in partial fulfillment of the requirements for award of Degree of Masters in Sustainable Energy Engineering.

By Eyuel Abate

Jimma, Ethiopia

may, 2018

Jimma University

Jimma Institute of Technology

Faculty of Mechanical Engineering

(Sustainable energy Engineering)

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By:
Eyuel Abate

Main Advisor: Proff.Doc.Venkata Ramaya
Co-Advisor: : Asst.Prof. Balewgize Amare

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DECLARATION

I, the under signed, declare that this thesis entitled by "*Impact Assessment and Design Modification of Mirt Stove to Mitigate Carbon Emission; in the Case of Jimma Zone*" is my original work, and has not been presented by any other person for an award of a degree in this or any other University, and all sources of materials used for the thesis have been duly acknowledged.

Eyuel Abate ______________________ ____________________

Name Signature Date

Venkata Ramaya (Proff) ______________________ _____________________

Advisor: Signature Date:

Balawgize Amara (Asst.Proff.) _______________________ _______________________

Co-Advisor**:** Signature Date

Approved by Board of Examiners

External Examiner _____________________ signature _______ Date _______

Internal Examiner _____________________ signature _______ Date _______

Chair Man _____________________ signature _______ Date _______

DEDICATION

This thesis manuscript is dedicated to all Ethiopian women who are suffering from baking and cooking food items on traditional three stone/three legs metal stoves.

ABSTRACT

The combustion process in traditional cooking stove is non-ideal and favors incomplete combustion. Incomplete and inefficient combustion produces significant quantities of fine and ultra-fine particles which have more global warming potential than Carbon dioxide. CO_2 is among the GHGs which contributes large portion to the ever increasing global warming, it is emitted from sources such as using biomass as fire wood. About 2.6 billion people rely on traditional biomass for home cooking and heating, hence improving the efficiency of household cook stoves can provide significant reduction in GHG emission.

Mirt stove is one of improved cook stove which is currently used for Injera baking and heating needs in Ethiopia. The aim of this study is to pave the way for the development of efficient and reliable improved mirt stove which can greatly mitigate the emission of carbon by changing the current design and by providing information on the current distribution and usage of stove. In this work experimental analysis as well as field survey is undertaken to assess the impact of improved cook stove (mirt midija) and it has been found that total of 10,816 tons of CO_2 is saved annually and in terms of pure carbon the saving will be approximated to be 2950 tons of carbon is saved annually.

Within this study Solid Works 2014 is used to model various geometries of mirt stove and a computational fluid dynamics (CFD) analysis has also been carried out for different newly designed geometries of stove to analyze the heat flow behavior over the stove body during the cooking period using CFD fluent 16 on Ansys.

After conducting the experiment on the conventional mirt stove the results for specific fuel consumption is found to be 220g/kg in average. Analytically using surface temperature measured and by considering each mode of heat transfer thermal efficiency is calculated and found to be 25%. Then using CFD analysis done on the same conventional mirt stove it has been found that the thermal efficiency is 34%. Finally for the newly designed stove with improved geometrical model, the CFD analysis is being carried out and a significant improvement on performance is obtained which is estimated to be 48.3% of thermal efficiency.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my bonafide work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfilment of the requirements of M.Sc. degree at Jimma Institute of Technology and is deposited at the University Library to be made available to borrowers under rules of the Library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma, or certificate.

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Place: Jimma Institute of Technology, Jimma

Date of Submission: …………………

Nomenclature

Symbol	
A	$Area$
E	$Energy$
m	$mass$
T	$Tempreture$
C_P	$specific\ tempreture$
d	$Diameter$
t	$Time$
V	$Velocity$
K	$Thermal\ conductivity$
f	$friction\ factor$
Q	$Heat\ transfer$
LHV	$lower\ heating\ value\ of\ wood$
HHV	$higher\ heating\ value\ of\ char$
h	$heat\ transfer\ \ coefficient$
ΔT	$change\ in\ tempreture\ from\ initial\ to\ final$
N_u	$Nusselt\ number$
P_r	$prandtle\ number$
R_e	$reynolds\ number$
σ	$stefan-boltzman\ constant$
μ	$viscocity$
ε	$Emissitivity$

BIOGRAPHICAL SKETCH

The author was born in September 1983 in Oromia Region, Illu Ababor Zone, mettu district from his mother Kebebush Degefu and his father Abate Lemma. He attended his elementary education at Abuna Petros elementary schools, and junior secondary education at Mettu senior and secondary school. He then joined the then Jimma University in November 2002 and graduated with B.Sc. degree in Mechanical Engineering in July 2006.

After his graduation, he was employed by the Ministry of education as an Assistant lecturer at Jimma institute of technology in October 2006 and has still been teaching different courses and taking responsibility for different duties in the College.

ACKNOWLEDGEMENT

Above all, I would like to thank the Almighty God for his immeasurable guidance in my entire life and for his free gifts to the world without them life would not exist. I am indebted to many individuals for their encouragement and help while conducting this study. First of all, I thank my major advisor Proff.Dr.Venkata Ramaya for his unreserved support in all aspect of my research work. He devoted his precious time and energy to comment and improve the research work starting from writing up my proposal up to the end. Equally, my gratitude goes to my co-advisor Mr. Balawgize Amara as he added valuable and constructive comments for successful accomplishment of the research work. Without their contribution, accomplishment of the research work truly would not have been possible.

I am very grateful to Jimma Institute of Technology for its provision of the necessary support and study leave. I highly appreciate the entire staffs under the school of mechanical engineering for their special support during data collection; particularly Mr. Surafel Kifle, Mr. Daniel Shitaye and Mr. Samuel Adisu are duly acknowledged. My exceptional thanks go to enumerators and the sample respondents for their helpful cooperation during data collection and experimental work for spending their precious time to accomplish my survey successfully.

This is a good opportunity to appreciate my family members; Abate Lemma, Kebebush Degefu, Tigist Abate, Solomon Abate, Hawi Gebeyehu for their moral and material support in my stay at Jimma University since my under graduate study. Moreover, my heartfelt thanks also go to my work colleagues of JIT for their special support that they gave to me during my research work.

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CHAPTER 1. INTRODUCTION

1.1 Background of the Study

In this world around 40% which is estimated as 2.6 billion peoples still relay on traditional biomass (wood, crop residues, dung, etc.) to meet household cooking needs (IEA 2012).Nearly three-quarters of these biomass users are in developing Asia, one-quarter in Africa, and the rest in Latin America and the Middle East; in some countries, such as Ethiopia, the Democratic Republic of Congo, Tanzania, Uganda and Bangladesh, over 90% of the population relies on these traditional cooking fuels (IEA 2012).

Additionally, nearly three billion people around the world burn coal or solid biomass (including wood, charcoal, agricultural waste, and animal dung) in open fires or inefficient stoves for daily cooking and heating. In addition to the health burden from smoke inhalation, burning solid fuels releases emissions of some of the most important contributors to global climate change: carbon dioxide, methane and other ozone producing gases such as carbon monoxide, as well as short lived but very efficient sunlight-absorbing particles like black carbon and brown carbon. Unsustainable wood harvesting also contributes to deforestation, reducing carbon uptake by forests.

Residential solid fuel burning accounts for 25% of global black carbon emissions, about 84% of which is from households in developing countries. In South Asia for example, where more than half of black carbon particles come from cook stoves, black carbon also disrupts the monsoon and accelerates melting of the Himalayan-Tibetan glaciers. As a result, water availability and food security are threatened for millions of people. These problems are compounded by crop damage from ozone produced in part by cook stove emissions and from surface dimming, as airborne black carbon intercepts sunlight.

Indoor air pollution from use of open fires and smoky stoves is a major health hazard, responsible for an estimated 2 million deaths per year (WHO 2011). Fuelwood collection can also pose risks to personal safety and keeps women and children away from school or income producing work, and it puts significant pressure on forests and scrubland. Moreover, traditional biomass burning produces greenhouse gases (GHGs) and black carbon, contributing to climate change.

By reducing these risks and pressures, improved cook stoves can yield numerous health, economic and environmental benefits. Moreover, cook stove projects can provide employment opportunities, both making and selling new stoves, and can contribute to technology transfer (Müller et al. 2011; Burridge et al. 2011).

Other benefits that accrue from increased use of improved biomass stove include the alleviation of the burden placed on women and children in fuel collection, freeing up more time for women to engage in other activities, especially income generating activities. Reduced fuel collection times can also translate to increased time for education of rural children especially the girl-child (Karekezi et al. 2002b). The provision of more efficient stoves can reduce respiratory health problems associated with smoke emission from biofuel stoves (Khennas et al. 1999; Karekezi and Kithyoma 2002).

Generally clean and efficient cooking stoves can reduce fuel use by 30-60%, resulting in fewer greenhouse gas emissions and reduced impacts on forests, habitats, and biodiversity. Recent evidence also demonstrates that advanced (efficient and low emission) cook stoves and fuels can reduce black carbon emissions by 50-90%. Since the atmospheric lifetime of black carbon is only a few days, reducing black carbon would bring about a more rapid climate response than reductions in carbon dioxide and other long-lived greenhouse gases alone.

Studies show that controlling both short-lived climate pollutants and long-lived greenhouse gases can increase the chances of limiting global temperature rise to below 2° C, a long-term international goal for avoiding the most dangerous impacts of climate change.

In a series of recent reports, the United Nations Environment Program emphasized the importance of introducing clean-burning biomass cook stoves and substituting traditional cook stoves with those that use modern fuels to mitigate climate change and improve air quality simultaneously.

According to a 2013 report by the Stockholm Environment Institute, the global potential for greenhouse gas (GHG) emission reductions from improved cook stove projects is estimated at 1 gigaton of carbon dioxide (CO2) per year.

This paper reviews existing cook stoves and their drawbacks regarding their effect on both the health and surrounding environmental and also performance analysis and carbon reduction potential of improved cook stoves are also discussed as a whole, generally by drawing a literature review as well as by analyzing the performance characteristics of the improved cook stoves the paper will describe or recommend the effective and efficient cook stove to mitigate carbon emission.

The overall objective of this empirical study is to assess the potential carbon impact of ICS in the Jimma zone. Specific research questions are: - What quantity of fuelwood is consumed in households per day where ICS are used, in comparison to households where conventional stoves are used? - What were the success factors for acceptance of ICS by the targeted households and what are the lessons learned for the implementation of fuel efficient stove projects? - What is the expected impact of the distribution of ICS on carbon emissions at the household and regional level?

1.2 Problem statement

Currently About 78% of the population in Ethiopia was still without access to electricity or any form of modern commercial energy (United Nations Industrial Development Organization (UNIDO) 2003, Developing Energy to Meet Development Needs, p 253). Today, over 85% of the rural population in Ethiopia does not have access to any form of modern commercial energy.

The inefficient, extensive and intensive use of fuel wood for cooking in particular puts a lot of stress on the environment and the family budget for those who buy. It also brings about indoor air pollution, deforestation and increased burden on women and children who spend considerable time in search for wood. According to John Beale, "it is a tragic irony that the very act of preparing food, which is designed to aid and nurture a family, is putting that very same family at risk" (Kounteya Sinha, 2007). They mostly rely on fuel wood and kerosene for cooking and lighting. The rate of electrification in 2004 was 13% and now has increased to 22%. This is a very commendable achievement, but still does not take Ethiopia out of the lower bracket of energy consumption, even in Africa.

On the figure below in the form of sketch represents the identified problem this thesis work aims at understanding and, to a greater extent solving. These problems fall within four major categories which include; health issues (indoor air pollution), environmental issues (deforestation and unsustainable use of fuel), social crisis (lack of electricity, poor living conditions, sex discrimination), Political issues (lack of well-structured governmental policies) and economic issues (affordability), and the general problem carbon emission resulted from an efficient usage of biomass fuel.

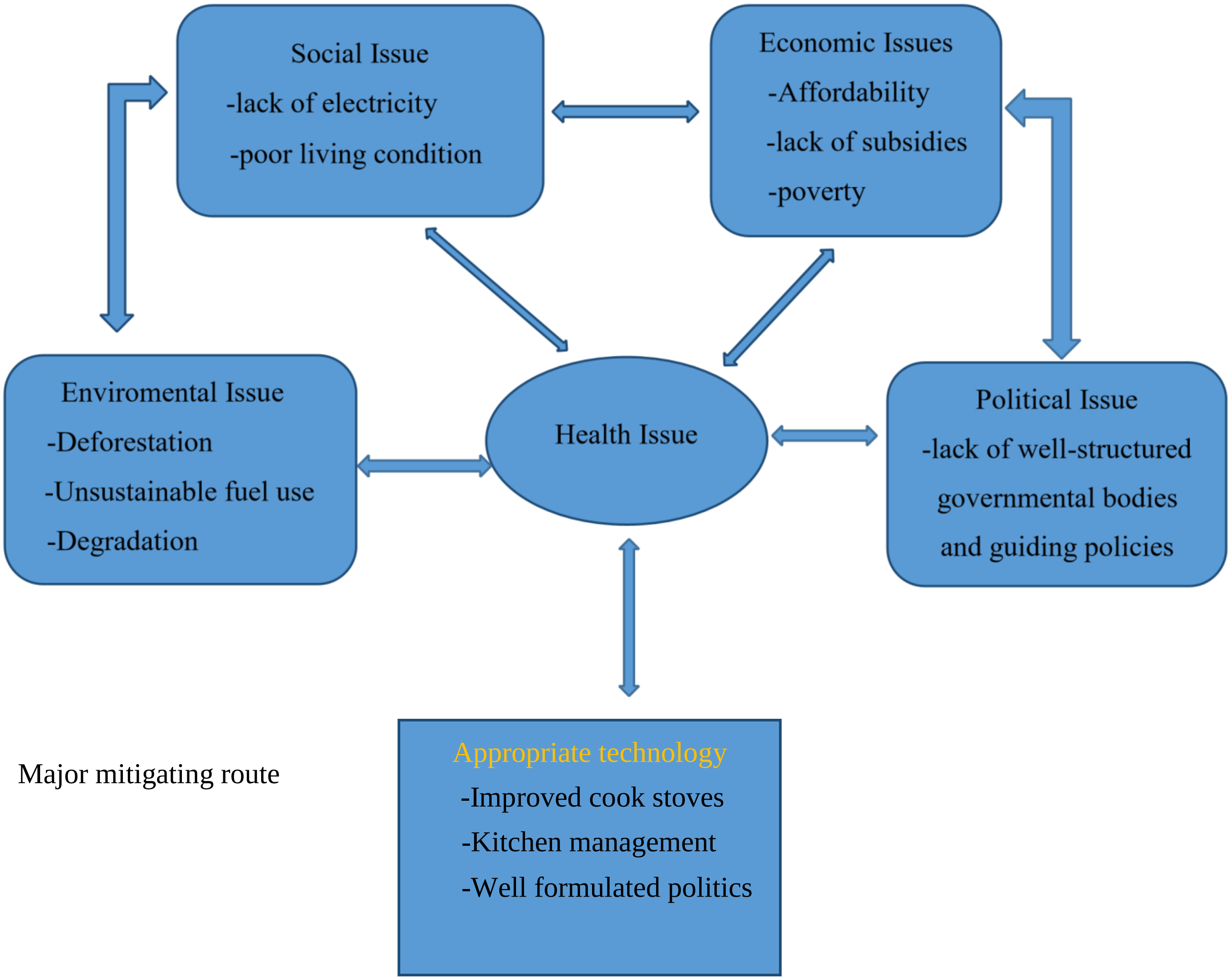


Figure 1.1 Schematic representation of the problem statement

Fuel wood in itself, is a renewable source of energy. However, when unsustainably exploited and used inefficiently, it causes terrible repercussions to human health and the environment. Dating many years, it was believed that only the poor who relied on fuel wood. Nowadays, formally rich are going back to fuel wood use while population increase plus urbanization all contribute to the increasing pressure on the forest.

In Jimma Zone, some of the most commonly used cook stoves include the three stone fire (figure 2), saw dust cookers (figure 3) and charcoal stoves (figure 4). They have serious health repercussions for users except where existing technologies are improved or better ones substituted. The real advantage of improved stoves is that they are safer and cleaner than open fires, reducing the risk of children burning themselves and cutting out the smoke inside the homes which damage health and dirties everything. They equally use less fuel thus reducing the level of deforestation. Even with these improvements, we cannot avoid all health problems, but at least one can mitigate the situation.

Generally, the rural communities in Ethiopia have low access to energy, both for subsistence and productive purposes, and rely almost entirely on biomass fuels. The consumption wood fuel has far exceeded its supply. Excessive dependence on biomass energy involves a trade-off in agricultural productivity, the crop residues and animal wastes being diverted from farms, where they supplement soil nutrition, to provide energy needs. Similarly, as wood scarcities has become increasingly serious, rural household who depend on collective free wood have to travel further distances to obtain wood fuel, thus causing loss of human availability for productive work. Furthermore, wood fuel depletion will further deforestation and lead to a general degradation. The prevailing pattern of energy supply and consumption shows many elements of unsustainability. The energy problem in the country arises not from excessive reliance on nonrenewable energy sources, but rather that one form of energy-wood fuel – is being consumed at an unsustainable rate.

Additionally, regarding the mirt stove currently under usage within the society has the problem with design because the mirt stove is not appropriate for the separate bought clay mitad, as these clay plates are produced traditionally by hand with unstandardized design, and these gap greatly affect the efficiency of the stove.

In this paper, attempt will be made to evaluate the amount of carbon mitigated or reduced by using the improved mirt midija stove within jimma zone will be discussed, and also further improvement will be done on the geometry of the stove , and thermal performance of modified or improved geometry of biomass mirt midija(stove) will also be conducted.

Additionally, mathematical models of the coupled heat and mass transfer of the baking process using the newly developed mirt stove will be developed and solved using the finite element analysis.

1.3 Expected Outcomes

The study is expected to pave the way for the development of efficient and reliable improved mirt stove which can greatly mitigate the emission of carbon by providing information on the current distribution and usage of mirt midija or stove and also these study asses the amount of carbon mitigated by using these improved cook stoves/mirt midija within the study area.

1.4 Objectives of the study/ research

Bearing in mind that biomass fuel will continue to play an important part in the energy mix of low-income households for some time to come, this research work has an objectives:

1.4.1 General Objectives

The overall objective of this empirical study is to assess the potential of improved cook stove (mirt midija) to reduce carbon emission in Jimma zone and to improve the efficiency of the existing improved cook stove or mirt midija for better performance.

1.4.2 Specific objective

1. To study the-state-of-the-art of cook stoves (three stone and mirt midija) by carrying out a comparative study of mirt midija and three stone stove in the case study area and to assess the impact of improved cook stove(mirt midija) in mitigation of carbon emission.
2. To carry out a stove performance test (CCT) by assessing the effect of wood moisture on combustion efficiency and heat transfer efficiency of mirt midija stove using the laboratory based controlled cooking test.
3. To assess/identify the problem or gap within the current improved cook stove mirt midija.

4. To assess the effectiveness of the current mirt midija/ stove and identify performance improvement opportunities, optimum alternatives to improve the current mirt midija.by analyzing the performance of different design models.
5. Designing and performance analysis of new design models of mirt midija
6. To develop analytical heat transfer analysis using Ansys CFD simulation software for an indication of further optimization opportunities.

Specific research questions are: -

1. What quantity of fuel wood is consumed in households per day where ICS are used, in comparison to households where conventional stoves are used?
2. What are the success factors for acceptance of ICS by the targeted households and what are the lessons learned for the implementation of fuel efficient stove projects?
3. What is the expected impact of the distribution of ICS on carbon emissions at the household and regional level?
4. What improvements are needed within the existing mirt midija stove

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; money and time saved in acquiring fuel; and reduced biomass use, ability to use animal dung as fertilizer instead of as fuel.

External benefits include less pressure on forest and energy resources; reduced GHGs; and skill development and job creation to the community.

Generally Switching to cleaner energy and increasing fuel efficiency and cleaner burning through better stoves can reduce carbon emissions and also reduces health risks for all family members. Beyond curbing respiratory problems, a more secure household energy situation enables water to be boiled and thus helps reduce the incidence of waterborne diseases. It can also increase the number of hot meals consumed per day and thus improve food safety and nutrition.

1.8. Methodology

A CFD codded software called ANSYS Fluent is chosen for this project because the development of such a computational model which uses detail simulation using computational fluid dynamics to predict the performance of the actual stove, and obtain the model equation that relate design and performance parameters and would also be useful in carrying out design optimization of a given type of biomass stove(mirt stove) for a given biomass fuel and also the heat transfer through the cooker will be analyzed using the CFD software. The development of the computational model involves the development and validation of sub-models of buoyancy induced fluid flow and heat transfer.

Wood burning Injera baking stove called mirt stove which is a natural draft is selected to develop a detailed computational zonal model of a heat transfer and fluid flow process, and also experimental analysis is conducted on this stove to assess the performance characteristics and to calculate energy balance in the stove. The basic equation used for mathematical modelling will be first law of thermodynamics to perform a mass and energy balance. A fundamental equation that demonstrates the interdependency between mass, flow rate, temperature and heat transfer in and out of the stove will be modeled.

Due to the different losses that occur in the stove study of different heat transfer process is very important and necessary to understand the mechanism of heat transfer in a cook stove. And finally after identifying major heat loss area the geometry of existing stove will be modified for better utilization of energy.

CHAPTER 2. LITRATURE REVIEW

2.1 What is Biomass?

Biomass is the term used to describe all the organic matter, produced by photosynthesis that exists on the earth's surface. Biomass is a renewable energy resource derived from the carbonaceous waste of various human and natural activities. It is derived from numerous sources, including the by-products from the timber industry, agricultural crops, raw material from the forest, major parts of household wastes and wood.

With its zero emission of CO2, biomass is one of the most potentially rich resources of energy that is yet to be tapped to the utmost extent. The source of all energy in biomass is the sun, thus biomass acts as a kind of chemical energy store. Biomass is constantly undergoing a complex series of physical and chemical transformations and being regenerated while giving off energy in the form of heat to the atmosphere.

Biomass does not add carbon dioxide to the atmosphere as it absorbs the same amount of carbon in growing as it releases when consumed as a fuel. Biomass recycles carbon from the air and spares the use of fossil fuels, reducing the need to pump additional fossil carbon from ground into the atmosphere. Biomass comes from green plants which actively absorbs carbon dioxide from the atmosphere and converts it into sugars, which are then stored in long molecules like cellulose. Eventually this plant carbon is returned to the atmosphere by natural decay process including the breakdown of cellulose. We can intervene in this process by breaking down cellulose to glucose in bio mass processing plants, and then converting the sugars to ethanol, which is a substitute for gasoline. Using ethanol made from biomass, sugars reduce the need for fossil fuels like gasoline. Ethanol can also be used to power fuel cells and is easier to store and distribute than gaseous hydrogen.

Its advantage is that it can be used to generate electricity with the same equipment or power plants that are now burning fossil fuels. Biomass is an important source of energy and the most important fuel worldwide after coal, oil and natural gas.

2.2 Energy situation in Ethiopia

Here by excluding human and animal energy, the sources of energy supply in Ethiopia can be classified into traditional and modern energy. Traditional sources include wood fuel, agricultural residue, and charcoal and cattle dung collectively known as biomass. It accounts to about 95.8% of the total energy supply of the country as the a whole. Modern energy consists of electricity and petroleum products, and accounts to the remaining 4.2% of the national energy supply sources. From the total modern energy supply, on average, petroleum constitutes 86% and the remaining 14% is derived from electricity, of which 96.7% is from hydro and 3.3% from diesel generators [1].

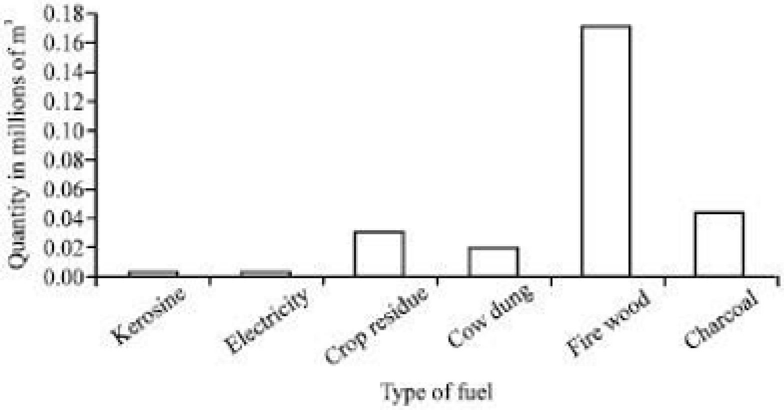
The supply of fuel wood is diminished from time to time with population growth. This led to the rural population to spend a large percentage of their time searching for fuel wood instead of performing productive work in agriculture. Fuel wood scarcity has led to a growing dependence on crop residues and animal dung as fuel, which otherwise would have been used as animal fodder and for the restoration of soil fertility. This could potentially lead to severe reduction in agricultural output at a time when greater production is expected in the sector. Similarly, shortages and high costs of fuel wood lead to the reduction in the number of cooked meals, especially by the urban poor who cannot afford to switch to modern fuels. This would have adverse health effects.

Generally, In Ethiopia, it is identified that biomass energy usage is a key issue in the national economy in general and the energy sector in particular. The underlying reason is that the cooking and baking is the major consumer of energy, and almost the entire energy demand of this sub-sector is met from a biomass resource. In many parts of the country, unsustainable exploitation of biomass resources has resulted in adverse economic and environmental impacts. Most of the resources (finance, labor and time) are over extended due to the rising prices of fuel and an ever increasing distance of fuel wood collection sites.

The fuel wood demand and supply projection and analysis specifically made in Jimma by researchers **Kiflu Haile, Mats Sandwell** and **Kaba Urgesa,** the finding displayed in the following table 1.1 shows, in the area about 0.062 million m^3 woods was consumed by the urban households whereas 0.133 million m^3 was consumed by the rural households. 0.011 million m^3 wood was consumed by urban non-household sector. The finding reflects as the rural households took the first line share in wood fuel consumption in comparison to urban household, the reason might be, the urban household had alternative modern fuels. In general, in the area 95% of the total wood fuel is consumed by the household sector where as 5% of the wood fuel was consumed by non-household sectors.

Table 1.1 Total wood fuel demand by sector in millions of m3 per annum

Target population	Total wood fuel consumed	Percentage by sectors
Urban household	0.062	
Rural household	0.133	
Subtotal	0.195	95
Urban non-household	0.011	5
Total	0.206	100



Source (http://scialert.net/abstract/?doi=rjf.2009.29.42)

2.3 Improved cook stoves

Improved Cook Stoves have to be adapted to the cooking habits of the stove users. The most common method of cooking used in developing countries is an open fire. The fire is usually shielded or surrounded by "three or more stones, bricks, mounds of mud, or lumps of other incombustible material" [2]. The three-stone fires have continued to be used for cooking and heating purposes, mainly due to their simplicity. They are easy to build and virtually free. They can be adapted to different forms quite easily – i.e. placed on waist-high platforms for more convenience for the user. There are more sophisticated types of traditional stoves, ranging from mud stoves to heavy brick stoves to metal ones. Most sources cite the fuel-efficiency of traditional stoves as 5 – 10% [2]

2.4 Stove development in Ethiopia

Biomass is an important energy source in Ethiopia. Biomass energy represents about 94% of total energy consumption. About 89% of the biomass energy supply is used by households. [3]

Given the low level of efficiency attained by traditional biomass technology used in the Ethiopian households, improving domestic cooking efficiency has been given emphasis. Cooking efficiency improvement has been carried out in Ethiopia by government and NGO's.

Since the 1970s the EREDPC, has been engaged in the business of improving household cooking efficiency, resulting in three improved cook stoves, namely: "Lakech" charcoal stove, "Mirt" fuel wood stove for making Injera (a large, flat bread (pancake) made of sour doughtaple diet in

Ethiopia), and the "Gonze" multi-purpose wood stove used for baking, cooking and boiling. [4] those stoves are again common in the research area or Jimma zone.

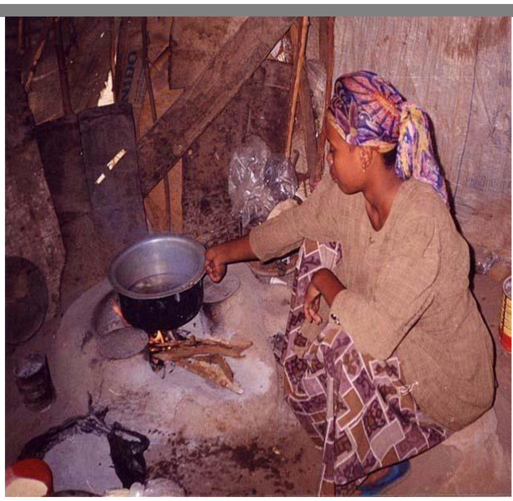


Figure 2.1 Wood-stove commonly used in Ethiopia (outers collection)

Figure 2.2 saw dust cooker stove (outers collection)

2.4.1 Charcoal stoves

Charcoal stoves are the most widely used for “Wat” cooking, water boiling, coffee making and other related activities in urban and semi urban area of Ethiopia. The use of these stoves increases with the rapid growth of urban population of the country. From an energy point of view, charcoal is not a positive conversion of wood. Even though traditional charcoal stoves are usually more efficient than traditional three-stone stoves, 60 – 80% of the energy is lost in the process of converting (typical kiln yields of 10 – 20% on a weight basis), thus negating any savings even from the more efficient stoves [5]. Charcoal stoves are light weight, portable, have one fire per pot, and have no chimney. Works in Thailand and Kenya indicate that the most important variables that affect the performance of the stoves are wall material (insulated pottery is best), the density of the ceramic material (which should be light and porous), the area of the grate hole (which should be about 76cm2 for a grate of 14 cm diameter), and the area of the exhaust gap [5]. The most fundamental components of charcoal stoves are briefly described as follow:

Primary air entrance: - Having a door to the primary air entrance allows some adjustment of the power output (in some designs a door is not included since it is not considered as necessary in practical). The power out-put can be increased by fanning air in the primary air inlet.

Grate: - The grate should have sufficient open area to allow good mixing of air underneath the charcoal. The openings should be less than 2cm wide to reduce the amount of small charcoal pieces that will fall through, but greater than 0.5 cm so that they will not get blocked. [6]

Combustion chamber: - The shapes of combustion chambers are slightly conical, in improved charcoal stoves, to keep the charcoal to be packed as it burns down & decreases the size [5].

Pot/pan seat: - The pot/pan usually sits with a 1 to 1.5cm gap for the exhaust gases, larger gaps allow more heat to escape. The pot seats are always made to accommodate a range of pot sizes. Many designs have metal supports if the combustion chamber is made of a weaker material. Similar to the air entrance door, it is also optional depending on the type of the stoves.

Stove body: - Different studies indicate that the weight of stoves has high correlation with efficiency, the heavier stoves have lower efficiencies. However, very light stoves which have low heat capacity walls (e.g. thin steel) do not attain high power outputs, high efficiencies or steady burning, without full combustion chambers. Insulating the combustion chamber with fired pottery, low density pottery, clay, ash mix, pumice stone, cement/vermiculite mixtures, or other heat resistant insulators, have usually increased the efficiency significantly. Insulating the outside of a cast-iron combustion chamber also increases the efficiency significantly [5].

Figure 2.3 common charcoal stove (source authors collection)

2.4.2 Lakech stove.

Lakech stove was adopted from the Kenyan Ceramic Jocko (KCJ), by the EREDPC of the Ministry of Mines & Energy in 1990 under the Cooking Efficiency Improvement & New Fuels Marketing Project.

The stove was optimized by thinning the metal cladding of KCJ to suit with the Ethiopian cooking habits & reduces construction cost. It has the shape double conic fitted with ceramic liner above its waist. A half liner combined with the bell-bottom shape provides stability to the stove, with a low cost and low weight as compared to full liners [1]

The “Lakech” charcoal stove has an efficiency of 19 – 21% and a fuel saving of 25% compared with traditional stoves. The stove is popular among urban dwellers and is used mostly for coffee making and cooking stew. To date over 2.5million stoves have been disseminated [7].

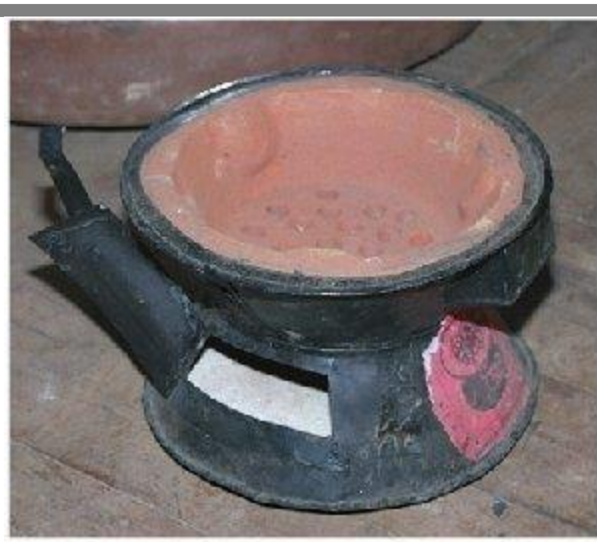


Figure 2.4 lakech stove (source authors collection)

2.5 Injera Baking System in Ethiopia

Preparation of Injera has a long process; it usually takes two to four days from mixing to cooking. It can be produced from almost any staple grain, with sorghum, millet and teff being the most common in Ethiopia. The teff flour is mixed with water and left to ferment for two to four days, but can take less than this time in warmer locations. Starter (left-over batter from the previous baking time) may be added to trigger fermentation. Approximately four to six hours before baking, a layer of bitter fermentation product is removed and hot water is added to reactivate fermentation, then the batter is poured on top of the hot baking pan surface.

To bake injera, the heat supplied to the baking pan either comes from burning fuel wood, dung or agricultural residue in biomass cookers, by heating electrical resistance in the electric baking pan and by means of heating heat transfer fluids for solar powered baking pan as the case in this particular thesis. This heat is then conducted through the baking pan to the surface where the batter is cooked.

The heat supplied to the Injera baking pan is used for raising the temperature of the batter on the pan surface from room temperature (20 to 25℃) to around boiling point of water. (In Addis Ababa, boiling point of water is about 92oc). Conventional baking pans are 58 - 60cm in diameter.

2.5.1 Injera Baking Using Open Fire System

In most of the households of the country, Injera baking is carried out using an open fire (three stone) baking system and the fuel is biomass. The heat supplied to the mittad in this system is lost through a variety of paths such as: through the sides, through the exhaust gases from the fuel, through convective and radiative heat losses from the pan surface. The fraction of energy that flows into the Injera batter is very small and therefore this technique is inefficient and wasteful; and also is unhealthy because it can damage the lungs and eyes of those in close proximity to the oven or fire.

Figure 2.5 open fire (three stone) Injera baking system (source; outers collection)

2.5.2 Mirt Injera Stove

Mirt is an enclosed Injera stove designed by the former Ethiopian Energy studies and Research center of the Ministry of Mines and Energy. The name Mirt means best. The basic design of Mirt is adopted from those of the Ambo and Burayu enclosed Injera stoves by optimizing to handle different types of fuels.

It is prefabricated stove from cement and local aggregate such as sand panels. The stove is suitable for mass production by casting the light concrete. Each mirt saves approximately 5 kg of wood per Injera baking session for the average household. Most household bakes Injera twice a week. Thus, the Mirt saves at average per household nearly 260 kg of wood a year [17]. This is a significant savings for the average Ethiopian urban household. However, the mirt saves commercial Injera bakers over 3.5 tons of fuel wood per year [17].

The stove comes in two versions, including the classic "Mirt" stove, which has thicker walls and the slim "Mirt" stove, which is lighter and more fragile. The classic stove has a lifespan of 5 years [8,9], while the slim version is conservatively estimated to last for 3 years. The stove has six parts. Four arcs which fit together to form the circular combustion chamber &Two-U-shapes that form circular pot rest. The four arcs of the combustion champers enable the stoves to avoid cracks due to thermal stresses & also help to handle & transport the stove easily. The U-shape part is used for pot rest & chimney purposes. Within the project, the stoves were offered free of charge, while the transportation was organized and paid by the end user (mean transportation costs 15 ETB; SD = 5.6; approximately $3 USD).

The "Mirt" 'Injera' stove has an efficiency of 16-21%. It has a fuel saving potential of 40-50% compared with traditional stoves. More than 1.2million Mirt stoves have been disseminated. [10]

Figure 2.6 Mirt Injera stove (source outers collection)

2.5.3 Electrical Injera Baking Pan /Mitad

Electricity is an important energy source, so the other type of technology for Injera baking is electric ‘’mitad’’; which is mainly used by people in the urban and near urban towns where electricity is available. Thus, the majority of population (more than 80%) in Ethiopia uses wood or biomass fuel for Injera baking.

Disadvantages of electrical baking system: -

a. If the source of energy is diesel fuel, it needs high cost and has contribution to the resource depletion and air pollution.
b. The electric baking system is used only for the urban areas where electricity is available; so that a lot of rural people do not have access of the electricity network.
c. There is high energy loss through the sides and bottom of the baking assembly; and also it has maintenance and labor cost.

Figure 2.7 Electrical Injera baking mitad assembly

2.5. What improvement is needed on their limitation

It is known that three stone inefficient end-use devices are used by the majority of Ethiopian households, mainly in the rural area. To decrease inefficient household fuel use, a lot of organization has been working on development and dissemination of improved stoves, to make available affordable fuel saving stoves to the rural areas; however, most of the stove users mainly semi urban households could not use it to cook. I.e. most users could not raise the plate from the stove to keep it safe from thermal cracking. It is also, the production and dissemination rate of the stoves mostly depends on its entrance of the consumer's house randomly.

From these and others point of views, it can be noted that, apart from fuel saving and affordability of the stove make an attractive appearance and more convenience of the stove have a significant implication on its marketability [13]. For the case of this study further improvements will be undertaken for the mirt midija by considering the following points related with Injera baking system within the study area;

- Affordability

- Electrical energy requirement where there is no grid connection
- Efficiency with respect to other traditional ways of Injera baking as well as cooking
- Addressing the rural area in general
- Reducing deforestation by efficient use of biomass

2.6 Review of current carbon market activity

Basically by improving the efficiency of the cook stoves and mitigating the carbon emission one can also involve in global carbon marketing mechanism, Carbon offsets play a role in both compliance and voluntary carbon markets. In compliance markets, such those created by the Kyoto Protocol or the EU Emissions Trading System, governments and regulated facilities have mandatory, legal emission obligations, and can use offsets, such as Certified Emission Reductions, as an alternative to reducing their own emissions.

The Clean Development Mechanism is currently the only program that can issue offsets from developing countries for use in compliance markets. In contrast, voluntary market offset programs such as the Gold Standard (GS), the American Carbon Registry (ACR), and the Verified Carbon Standard (VCS) issue offsets that can be used by businesses, governments, NGOs, and individuals electing to offset their emissions for other reasons, such as corporate or individual social responsibility.

All four of these programs (and no others) have enabled crediting of emission reductions from improved cook stove projects. Each has approved methodologies or protocols that specify eligible technologies and project types, and the means by which projects are monitored and their emission reductions quantified. The methodologies apply to projects that are introducing a stove technology and consider the emissions savings from reducing or displacing the use of nonrenewable biomass for household heating and cooking. [14]

2.7 Review of previous studies related with the study topic

Internationally there have been various studies conducted about both on mitigation of carbon emission by adopting of improved cook stove as well as researches done on an improvement of mirt midija mitad or pan. Elisabeth D, Ben.D , varies, Martin.H, Lius.V, Robert.M 2014. Studied about the impact of improved cook stove specifically mirt midija in the case of reducing the carbon emission in Afromate forest Ethiopia. They identified the possible projection of consumption of various fuels and also analyzed the possible amount of carbon that could be mitigated if an improved cook stove is further disseminated within the area. And finally they recommended that further study on mitigation of carbon emission by using improved cook stoves like mirt midija on the areas where the forest coverage is less will have a greater importance in the reduction of carbon emission.

Daniel.M.kammen 2011 also studied about the effect of incomplete combustion with biomass wich will resulted in both increasing emission rate of GHG as well as health problems related with un improved cook stoves. On his study he tray to assess the current problems mainly arises because of the usage of un improved cook stoves as well as poor cooking tradition within the society, to alter those problems Daniel M Kammen highly recommended the development of improved cook stoves specially those can help in the case of reducing the amount of carbon emitted because of un effective use of the biomass. [10]

Adeyemi Kafayat phd,2014 also mentioned the significance of using improved cook stoves in the case of possible emission reduction that can be further traded in the carbon market (provided, approved methodologies, monitoring and verification procedures have been adopted) there by achieving sustainable development through carbon finance whilst mitigating climate change. [18]

The research done by an organization called global alliance for clean cook stove 2011, states that burning solid biomass with an efficient cook stoves resulted in release of pollutants that can contribute to climate change at regional and global levels. In particular, the researchers mention that some of pollutants, such as black carbon and methane have short life span but significant consequence for the climate. From these it is estimated that CO_2 which ranges from 25 – 50 % contributes in warming globally

The research also mentioned that the universal adaption of advanced biomass cook stoves could have an impact equivalent to reducing CO_2 emission by about 25 – 50%.

In a serious of recent report, the united nations environmental program emphasized the implementation of introducing clean burning biomass cook stoves and substituting traditional cook stoves with those that are improved cook stoves.

Furthermore, with respect the efficiency or improvement of the mirt midija/stove the following literatures are assessed as follows,

A research conducted in sirilanka(P.P.S.S. Pussepitiya and S.U. Adikary), Optimum thermal shock resistance of 0.74 kJm-1s-1 was achieved for a body composition of 45% of clay, 15% of talc, 15% of alumina and 25% of zirconium silicate which was fired to 12500C [18]. Further, modulus of rupture and coefficient of thermal expansion of the ceramic body were 74 MPa and 30.2×10-7 K-1, respectively. These results suggest that composite body is suitable to be used in cookware mitad applications for greater stove efficiency as the whole. This research is based on a newly manufactured composite plate/mitad with a body composition of clay and metal chips with the goal of increasing the thermal conductivity of the pan.

A previous research conducted by Garadaw Ambaw 2015, states that the ceramic bake ware with 2.6cm thickness reaches baking temperature of 150℃ after 20.5 min of heating and gives 1.996MJ/kg of overall energy intensity. This value is 1.79 MJ/kg for the conventional clay mitad. The difference is due to the increased thickness of the current mitad used for the test. It is seen that good qualities of Injera were obtained at baking surface temperature of 147 to 150℃; above this it was found to reduce the quality of the product both at the bottom and top surfaces [19]. Regarding the effectiveness and reliability of the stove while excellent baking quality of Injera was observed for all cycles of baking, crack was observed at the surface of the bake ware. The increased thickness of the new mitad and the presence of thicker edge boundaries produce temperature gradient across the thickness and the radial direction; which results in a thermal stress gradient in the body causing crack to commence and propagate at the top surface radial end locations. And finally he recommended that the reduced thickness and increased thermal conductivity of the mitad/ pan will result in a greater efficiency of the clay mitad specifically.

This research or study basically depends on the previous works of Elisabet D, Ben.D and Martin.H, 2014 on which they studied about the impact of improved cook stove specifically mirt midija in the case of reducing the carbon emission. Their study findings show that the possible amount of carbon that could be mitigated if improved cook stoves like mirt midija is used specifically within the area where the forest coverage is lesser.

With respect to stove modification this research also depends on the previous works of Garadaw Ambaw (2015) and Assefa Ayalew (2009) on which both recommended that efficiency of the stove can be improved by modifying the geometry of the stove which incase results in increasing of the thermal conductivity of the material as well as by reducing the thickness of the plate or pan. Based on these findings new design models of mirt midija including the structure of the stove will be designed and assessed by ANSYS cfd analyzer and finally used for the proposed new type mirt stove system.

CHAPTER 3. EXAMINING MIRT STOVE BY EXPERIMENT AND CFD

3. Introduction

Within this respective chapter the performance of mirt stove is studied by conducting experimental analysis which is controlled cooking test (CCT) and by means of computer based software computational fluid dynamics of the stove is conducted. The main work under taken in experimental analysis is experiments specific to stove, namely controlled cooking test, other correlated tests like durability test is already conducted by non-governmental organization called GIZ. The heat transfer characteristics of mirt stove is modeled in fluent using the considerations; 3D, incompressible and laminar flow.

This chapter also includes the necessary governing equation that Fluent uses to solve the flow in the biomass cook stove (mirt stove) along with the method of numerical computation of the flow variables which describes the numerical approach to solve the flow variables during CFD simulation.

Also the geometry of biomass cook stove (mirt stove) which is modeled by solid work and its detail components are mentioned within this chapter. During the CFD simulation major steps are followed to set boundary conditions used for simulation of fluid flow and heat transfer. Steps used to conduct the controlled cooking test is also specified within this chapter

3.1 Thermal characteristics of mirt stove.

Stove characteristics are specified by burning rate, firepower, turn-down ratio and the measure stoves commonly uses are Efficiency and performance measures which include time to boil, specific fuel consumption, thermal efficiency and Emission measures like emissions per fuel burned, emissions per MJ, emissions per task

Burning Rate – A measure of the average grams of wood burned per minute during the test.

Firepower – Firepower is a measure of how quickly fuel was burning, reported in Watts (Joules per second). It is affected by both the stove (size of fuel entrance/combustion chamber) and user operation (rate of fuel feeding). Generally, it is a useful measure of the stove's heat output.

Turn-Down Ratio – Turn-Down ratio indicates how much the user adjusted the heat between high power and low power phases. A higher value indicates a higher ratio of high power to low power, and could signal a greater range of power control in the stove. However, this value reflects only the amount of power control that was actually used.

Thermal Efficiency

Thermal efficiency is a measure of the fraction of heat produced by the fuel that made it directly to the water in the pot. The remaining energy is lost to the environment. So a higher thermal efficiency indicates a greater ability to transfer the heat produced into the pot. While thermal efficiency is a well-known measure of stove performance, a better indicator may be specific consumption, just by considering the average value of the control cooking test (CCT). This is because the test which is very slow in performance may have very good looking temperature efficiency (TE) because the cooking rate is good in respect of performance. However, the fuel used per cooking test remaining may be too high since the cooking performance is great and so much time was taken while bringing the pan(plate) to a cooking Efficiency is one of the most common metrics taken from the controlled cooking test. The test is supposed to help stove designers understand how well energy is transferred from the fuel to the cooking pan. However, the measurement of energy transfer is incomplete, leading to a misrepresentation of thermal efficiency. The energy transferred to the food is actually the sum of the latent heat, sensible heat, and the heat transferred away from the pot via convection, conduction, and radiation.

3.1.1 Testing performance of biomass cook stove

The performance of a biomass cook stove (mirt stove) can be characterized in two categories thermal performance and emission performance. Thermal performance is measured in terms of fire power or input power of the cook stove, specific fuel consumption, efficiency and turn down ratio, while emission performance is measured mainly in terms of emission ratio so emission factors of pollutants. Performance of biomass stoves shows a strong dependence on operation parameters, characteristics of the fuel used, sizes and types of pots used, the type of cooking process, ambient conditions, the ventilation levels, etc. This gives rise to the need for precise definition of the various performance parameters on one hand, and on the other, it necessitates reporting of the operating conditions precisely, while presenting the experimental results.

3.1.2 Methodologies

3.1.2.1 Water boiling test

The WBT consists of a high-power phase and a low power phase. The former simulates rapid cooking tasks such as water-boiling for making tea, while both the high power and low-power phases are required to simulate cooking tasks like cooking rice, beans or hard grains. Exploring stove performance at both high and low power output gives some indication of how a stove performs in a range of cooking conditions. In addition, the WBT provides a range of stove performance indicators: thermal efficiency; fuel consumption, and time to boil a fixed quantity of water.[24]

3.1.2.2 Kitchen Performance Test

As with studies of indoor air quality described in this issue, KPTs can be designed as cross-sectional or before-after studies. . The before-after study design permits stove testers to use a smaller sample size than the cross-sectional method for a desired level of statistical significance. Circumstances differ between stove projects, however, and so the testing methods must be adapted to suit the conditions in the field. The

Kitchen Performance Test (KPT) is the principal field–based procedure to demonstrate the effect of stove interventions on household fuel consumption. There are two main goals of the KPT:

1. To assess qualitative aspects of stove performance through household surveys and,
2. To compare the impact of improved stove(s) on fuel consumption in the kitchens of real households.

To meet these aims, the KPT includes quantitative surveys of fuel consumption and qualitative surveys of stove performance and acceptability. This type of testing, when conducted carefully, is the best way to understand the stove’s impact on fuel use and on general household characteristics and behaviors because it occurs in the homes of stove users (Lillywhite, 1984; VITA, 1985). However, it is also the most difficult way to test stoves because it intrudes on people’s daily activities. In addition, the measurements taken during the KPT are more uncertain because potential sources of error harder to control in comparison to laboratory-based tests. For this reason, the protocol for the KPT is quite different from the protocols for the Water Boiling Test (WBT) and the Controlled Cooking Test (CCT).[22]

3.1.3 Controlled cooking test. (CCT)

In order to evaluate the performance of the stoves Controlled Cooking Test (CCT) method was employed. The Controlled Cooking Test (CCT) is designed to assess the performance of the improved stove relative to the common or traditional stoves that the improved model is meant to replace. Stoves are compared as they perform a standard cooking task that is closer to the actual cooking that local people do every day.The testing protocol prepared by Rob Bails for the Household Energy and Health Program, Shell Foundation has been used. With chosen experienced cook, Injera baking has been selected as a cooking task for the test.

The CCT data calculation sheet developed consists of three testes which are conducted by using different weight ratio of biomass fuel and dough procedures also the equation or formula used to calculate thermal efficiency, burn rate, and specific fuel consumption, time to cook and also fire power are discussed in detail. The calculation excels data work sheet for CCT is shown on appendix-1 of this paper.

The three tests conducted in controlled cooking test. This combination of tests is intended to measure the stove's performance at different weight ratio of biomass fuel and cooking dough, which are important indicators of the stove's ability to conserve fuel.

Although based on a simpler concept than the WBT, the KPT is more difficult for organizations to conduct in practice because of complicated sample selection procedures and logistical issues of working in real households. The former are particularly important because the variability in measurements of household fuel consumption tends to be higher than the variability observed in lab based testing, hence larger sample sizes are needed to obtain statistically significant results. Some groups could not overcome this difficulty and followed different procedures.

Another difficulty with the KPT was that it was originally designed to accommodate only wood-burning cook stoves while many households use agricultural residues of various kinds. Another difficulty with the KPT was that it was originally designed to accommodate only wood-burning cook stoves while many households use agricultural residues of various kinds.

Variables which are constant.

HHV – gross calorific value (dry wood) (KJ/kg) higher heating value (also called gross calorific value). This is the theoretical maximum amount of energy that can be extracted from the combustion of the moisture free fuel if it is completely combusted and the combustion products are cooled to room temperature such that the water produced by the reaction of the fuel-bound hydrogen is condensed to the liquid phase.

For this experiment the **HHV** value of wood used for the analysis is **19,500KJ/Kg**.

LHV – net calorific value (dray wood) (KJ/Kg); lower heating value (also called net heating value). This is the theoretical value. This is the theoretical maximum amount of energy that can be extracted from the combustion of the moisture-free fuel if it is completely combusted and the combustion products are cooled to room temperature but the water produced by the reaction of the fuel-bound hydrogen remains in the gas phase.

For this experiment the **LHV** value of wood used for the analysis is **18,595KJ/Kg**

MC ; wood moisture content (% -wet basis); this is the % wood moisture content on a wet basis; defined by the following formula;

$$MC = \frac{mass\ of\ wet\ fuel - mass\ of\ dry\ fuel}{mass\ of\ wet\ fuel} \quad (3.1)$$

MC is a decimal fraction which is formatted in the controlled cooking test(CCT) spreadsheet as a percentage. Therefore, for this study if the value of **MC** on the spreadsheet is 15%, a value of MC = 0.15 is used for the calculations.

3.1.4 Variable which are calculated from the measured result and constant parameters.

$\boldsymbol{F_d}$- equivalent dry wood consumed the fuel consumed (moist) is the mass of wood used in the first test, found by taking the difference of the pre- weighed bundle of wood and the wood remaining at the end of the test phase, or it can be also be found as defined for the WBT, adjusting for the amount of wood that was burned in order to account for two factors: (1) the wood that must be burned in order to vaporize moisture in the wood and (2) the amount of char remaining unburned after the cooking task is complete. The calculation is done in the following way:

$$F_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c \quad (3.2)$$

$\boldsymbol{\Delta C_C} -$ the net change in char during the test is the mass of char created during the test, found by removing the char from the stove at the end of the test phase. The char will be placed in empty pre-weighed container of mass K (to be supplied by the testers) and weighing the char with the container, then subtracting the container mass from the total.

$\Delta tc -$ This is also an important indicator of stove performance in the CCT. Depending on local conditions and individual preferences, stove users may value this indicator more or less than the fuel consumption indicator. This is calculated as a simple clock difference:

$$\Delta t = t_f - t_i \quad (3.3)$$

$W_f -$ total weight of food cooked; this is the final weight of all food cooked; it is simply calculated by subtracting the final Injera or food after the cooking task is complete from weight of the dough prepared for the cooking process.

$$W_f = P_f - P_i \text{ .... } (3.4)$$

$F_{cd} - the\ equivalent\ dry\ fuel\ consumed$ this is an equation which adjusts the amount of dry fuel that was burned in order to account for two factors; (1) the energy that was needed to remove the moisture in the fuel and (2) the amount of char remaining unburned. The mass of dry fuel consumed is the moist fuel consumed minus the mass of water in the fuel:

$$Dry\ fuel = f_{cm}(1 - MC) \text{ .... } (3.5)$$

The energy that was needed to remove the moisture in the fuel ($\Delta E_{H2O,C}$) is the mass of the water in the fuel multiplied by the change in specific enthalpy of water.

$$\Delta E_{H2O,C} = \Delta m_{H20,c}\left(C_P\left(T_b - T_{fuel,initial}\right) + \Delta h_{H20,fg}\right) \dots\dots\dots\dots\dots\dots\dots\dots . (3.6)$$

$$C_P \approx 4.186 \frac{kJ}{kgK} \qquad \Delta h_{H20,fg} \approx \frac{2{,}257kJ}{Kg} \qquad T_{fuel,initial} \approx T_a$$

The mass of water in the fuel is; $\Delta m_{H20,c} = f_{cm}MC$

Therefore the above equation will be rewritten as; $\Delta E_{H2O,C} = f_{cm}MC(4.186(T_b - T_a) + 2{,}257)$

The quantity of energy is divided by the energy content of the fuel to determine the equivalent mass of fuel required to remove the moisture in the fuel:

$$\text{Fuel to evaporate water} = {\Delta E_{H2O,C}}/{LHV} \dots\dots\dots . \dots\dots\dots . \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.7)$$

The quantity of energy is divided by the energy content of the fuel to determine the equivalent amount of unburned fuel remaining in the form of char:

$$\text{Fuel in char} = {\Delta E_{char,C}}/{LHV} \text{ .... } (3.8)$$

Putting it together will give the following final equation.

$$f_{cd} = dry\ fuel - fuel\ to\ evapotrate\ water - fuel\ in\ char$$

$$f_{cd} = fc\ m(1 - MC)\ \frac{fcm\ MC(4.186(Tb - Ta) + 2.257}{LHV} - \frac{\Delta Cc\ LHV\ char}{LHV}$$

$$f_{cd} = \frac{fcm\ \left(LHV\ (1 - MC) - MC\ (4.186(Tb - Ta\ ) + 2.257)\right) - \Delta Cc\ LHVchar}{LHV} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.9)$$

$\eta - thermal\ efficiency$: it is the ratio of the work done by heating and evaporating water to the energy consumed by burning fuel. It is an estimate of the total energy produced by the fire that is used to heat the pan (plate) on which the Injera is baked

$$\eta = \frac{\Delta E_{H2O,heat} + \Delta E_{H2O,evaporated}}{E_{released,c}} \ldots\ldots\ldots \ldots\ldots\ldots \ldots\ldots\ldots \ldots\ldots(3.10)$$

The energy to heat the water is the mass of water multiplied by specific heat capacity times change in temperature:

$$\Delta E_{H20,heat} = m_{H20} C_p \Delta T \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.11)$$

The specific heat capacity is expressed as the following approximation.

$$C_p \sim 4.186 \frac{KJ}{KgK}$$

$$\Delta E_{H20,heat} = (P1_{Ci} - P1)\ 4.186\left(T1_{Cf} - T1_{Ci}\right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.12)$$

The energy to evaporate the water is the mass of the water evaporated multiplied by the specific enthalpy of vaporization of water:

$$\Delta E_{H20,evaporated} = W_{cv} \Delta h_{H20,fg} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.13)$$

As explained in the EHV equation above, the specific enthalpy of vaporization can be approximated as;

$\Delta h_{H20,fg} \approx 2{,}260 kJ/Kg$ and

$$\Delta E_{H20,evaporated} = W_{cv} 2{,}260 KJ/Kg$$

The energy consumed is the equivalent mass of dry fuel consumed multiplied by the heating value:

$$E_{released} = f_{cd} LHV$$

Putting the above equation together;

$$\eta = \frac{4.186(T_{1Cf} - T_{1Ci})(P_{1Ci} - P_1) + 2260 w_{cv}}{f_{Cd}\, LHV}$$

Thermal efficiency is actually a unit less decimal fraction but it is formatted in excel as a percentage.

$R_{cb} - burning\ rate$; this is a measure of the rate of fuel consumption during the baking process. It is calculated by dividing the equivalent dry fuel consumed by the time of test.

$$R_{cb} = \frac{F_{cd}}{\Delta t_c} \qquad (3.14)$$

$SC, specific\ fuel\ consumption$; this is the principal indicator of stove performance for the CCT. It tells the tester the quantity of fuel required to cook a given amount of food for the standard cooking task. It is calculated as a simple ratio of fuel to food:

$$SC = {}^{f_d}/_{w_f} * 1000$$

3.1.5 Equipment used for the experimental procedure.

The equipment required to conduct a serious of CCT is similar to the equipment required to conduct the WBT, in addition sufficient amount of biomass wood is required to conduct the experiment. This is discussed in more detail below;

1. Fuel; a homogenous mix of air dried fuel wood,
2. Dough and water; sufficient dough and water needed for the entire test will be prepared.
3. Injera baking pan (local clay pan or mitad)
4. thermometer, to record ambient temperature and to measure specific temperature value on different spots of both the plate (pan) and the stove)
5. Wood moisture meter or oven for drying wood and scale for weighing (moisture meter is less accurate, especially for very wet fuel wood).
6. timer
7. tape measure for measuring wood and stove (cm)
8. mirt stove both the slim version and the thicker one.
9. Small shovel/ spatula to remove charcoal from the stove.
10. Metal tray to hold charcoal for weighing
11. Dust pan for transferring charcoal.
12. Heat resistant gloves

3.1.6 Procedure of the experiment.

Controlled cooking test (CCT), according to the protocol of the University of California-Berkeley (UCB), is employed here in the test [21]. The corresponding data entry and calculation spreadsheets were utilized. The goal of such test is basically to get the value of specific fuel consumption of a stove, which is the amount of fuel used to produce a unit amount of food expressed in units of g/kg[22]. This is the main parameter used to assess the performance of the stove as well a way for comparing the improved stove against the baseline stove. The total time of producing a certain amount of food is also a measure of stove performance. Therefore, total time of production of Injera was recorded for each of the baking sessions.

To see how long, it would take the stoves before they would allow baking the first injera, during some of the tests, time was also recorded when the first pouring of dough on the mitad was done. Whenever possible, injera production time for each baking cycle (i.e. for baking one injera) was recorded as well.

Other observations such as the users' perception on the stoves in general on the whole baking practice had also been noted. A systematic record was not done but temperatures on different spots of the mitad before and after each Injera baking as well as during the initial heating of the mitad were monitored.

Following the protocol, at least three rounds of test are required and that was done accordingly. Whenever a test shows inconsistent result with others, it was re-done. And design modifications (such as chimney height increase or reduction) may necessitate more tests as well.

Figure 3.1 Butter and wood biomass weight being measured using electronic mass balance

Figure 3.2 By using infrared thermometer the initial and final temperature of the stove were recorded

Figure 3.3 When the Injera baking process has undertaken

Figure 3.4 Procedures followed during experiment.

The following quantities were recorded during the tests:

- Mass of firewood (before and after each test)
- Moisture of firewood
- Time the stove was lit (when the fire catches)
- Time when the first pouring of dough took place (not for all the tests)
- Time the test ends (normally is the time when the last injera is removed off the mitad)
- Mass of charcoal remaining
- Mass of Injera baked
- Number of Injera baked

● Mass of dough used to bake Injera

● Time to bake each Injera (not for all the tests)

● Time to heat the mitad before the next Injera was going to be baked (not for all the tests)

On slim version mirt stove the common practice of baking Injera in a common household, which is producing 25-30 Injera per stove per session utilizing close to 16kgs of dough was applied. Generally, the numbers of Injera falls in the aforementioned range. But the actual number depends on how viscous the dough is and how thin the Injera is. These in turn depend on the individual who prepares the dough and doing the baking, respectively. The range of the numbers of Injera is, anyway, what a typical Ethiopian household would bake per session.

1. The first step of the experimental analysis will be determining the type and characteristics of fuel used. The type, size and moisture content of fuel have a large effect on the outcome of stove performance tests. Because of this solid fuel should be well dried and uniform in size. Fuel wood with the size of 1.5 x 1.5 cm to 3 x 3 cm is suggested.
2. To ensure the safety and health of the tester, a breathing mask an eye protection should be used.
3. Record the type of stove used, size and shape also
4. Record local condition as instructed on the data and calculation form.
5. Weigh the predetermined ingredients needed during the experiment and do all of the preparations.
6. Start with a pre-weighed bundle of fuel that is roughly the amount that local people consider necessary to complete the cooking task.
7. Starting with a cool stove, allow the baking(s) to light the fire in a way that reflects local practices. Start the timer and record the time on the data and calculation form.
8. While the baking process performed, record any relevant observations and comments during the experimental process.
9. When the task is finished, record the time in the data and calculation form.
10. Measure and record the mass and number of Injera baked during the experiment.
11. Remove the unburned wood from the fire and extinguish it. Knock the charcoal from the ends of the unburned wood. Weigh the unburned wood from the stove with the remaining

wood from the original bundle. Place all of the charcoal in the designated tray and weigh this too. Recording both measurements on the data and calculation form.

12. Now the test is complete, each stove should be tested at least 3 times.

3.1.7 Result of the experiment

Mirt stove (slim version)

- The average specific fuel consumption of the stove is 220g/kg.
- The average total time used for baking Injera using the standard amount of 16kg dough has been found to be 95minutes.
- Average Baking time per Injera is recorded as 2.3minutes
- For the mitad average reheating time is 0.7minutes.
- These sum to an average cycle time per Injera is 3 minutes
- The stove performed slightly better when a centimeter or so of ash was left in the base of the combustion chamber. This meant slightly less air passing up through the grate which seemed to improve combustion and ease of lighting.
- During the light-up stage sometimes large quantities of smoke were produced but once the stove warmed up there was little visible smoke.

Table 3 .1 Measured data for energy balance calculation.

No	Measured surfaces	Average temperature(degree c)
1	Temperature of mitad surface	176
2	Flue gas temperature	332.5
4	Temperature at the sides of stove(inner)	222.7
5	Temperature at the sides of stove(outer)	103.6
6	Flue gas temperature through chimney	243.5
7	Temperature of the chimney(internal)	204
8	Temperature of the chimney(outer)	95.35
9	Temperature at the edges of each stove part	70.95
10	Temperature of wood surface during combustion	147.5

The data collected from the experiment will be inserted in CCT work sheet to get the numerical value of the thermal efficiency, specific fuel consumption and fire power used to bake Injera by using this biomass Injera baking stove

Also the energy balance of the stove will be calculated by measured surface temperature values of this experiment and the detail analysis of the energy balance will be discussed in the next chapter of this paper.

The following table shows summary of test results for mirt stove (slim version).

Table 2.2 Summary of present test results for mirt stove with injera baking

CCT results: Mirt stove.	Units	Test 1	Test 2	Test 3	Mean	St dev
Total weight of food cooked	G	7816	8024	7807	7882	123
Weight of char remaining	G	152	237	257	215	56
Equivalent dry wood consumed	G	1736	1619	1855	1737	118
Specific fuel consumption	g/kg	222	202	238	220	18
Total cooking time	Min	81	98	107	95	13

The above experimental result has been done with the respective study area (jimma), through the experimental process the following basic atmospheric conditions are put under consideration;

- Longitude and latitude of the study area, 7°, 33 N and 36°, 57' E at an altitude of 1710 meter above sea level.
- Density of air at the specific location 0.98kg/m^3
- Atmosheric air pressure 82kpa
- Ambient atmospheric tempreture 22ºc

The result CCT output result is compared with the CCT result that has been done by GIZ on mirt stove previously [22], and the comparision showed that there is slight diffrence with the output result of the experiment with respect to specific fuel consumption, the diffrence mainly arises due to the following factors;

- The amount of fuel wood used during experiment
- The amount of butter used
- The specific location on which the experiment has understaken
- Diffrence in atmospheric condition like density of air, atmospheric air pressure and ambient atmosheric air tempreture.

CCT results: Scoria-SM	**units**	**Test 1**	**Test 2**	**Test 3**	**Mean**	**St Dev**
Total weight of food cooked	g	10640	10750	10430	10607	163
Weight of char remaining	g	760	810	1220	930	252
Equivalent dry wood consumed	g	5528	5473	5256	5419	143
Specific fuel consumption	**g/kg**	**520**	**509**	**504**	**511**	**8**
Total cooking time	**min**	**129**	**124**	**133**	**129**	**5**

CCT result done by GIZ.

Generally the CCT experiment done on mirt stove within this study has an output result that is comparatively proved with respect to the CCT experiment already done by the GIZ organization, which follows the standard procedure in conducting the experiment too.

3.2 Properties analysis for the selected wood biomass

Biomass

Biomass is a renewable energy technology and it is classified as carbon neutral. As a tree grows they absorb carbon from the atmosphere and produce oxygen. This carbon is stored in the tree, if the was left to decompose, this captured would be released back to the atmosphere over a few years, burning that material will also release the carbon but will make use of the energy in the process.

3.2.1 Combustion of biomass

Combustion has three requirement fuel, air and heat, if any of these three are removed burning stops. When all three of them are available in the correct proportion combustion will be sustained, these is because of the fuel releases excess heat to initiate further burning within a given system.

An efficient combustion requires sufficient.

- High temperature
- Excess air(oxygen)
- Combustion time and mixture.

3.2.2 Proximate and ultimate analysis of wood biomass

3.2.2.1 Proximate analysis

The proximate analysis is determination of moisture content, fixed carbon, volatile matter and ash content of the sample. It sometimes includes the heat of combustion of the sample, ASTM method (3173 - 87) [ASTM,1989].

3.2.2.2 Ultimate analysis

The ultimate analysis provides the composition of elemental carbon, hydrogen, oxygen, nitrogen and sulfur for a combustible sample (ASTM D3177-84). A number of investigators have found that the elemental composition determined in the ultimate analysis is closely related to the heat of combustion [Tailman,1978, IGT 1976, Graboski,1981].

The following table shows the detail ultimate analysis for the selected biomass in Ethiopia with 15% moisture content.

Table 3.3 ultimate analysis of selected biomass

Element	Measured values
Carbon	48.00%
Hydrogen	5.7 %
Oxygen	30%
Nitrogen	0.5%
Sulfur	0.05%
Ash	0.75
Moisture	15%
Total	100%

Source: laboratory report of Ethiopian rural energy development and promotion center (EREDPC)

3.2.3 Determination of Lower heating value(LHV) and higher heating value(HHV) for eucalyptus galipots tree.

3.2.3.1 Higher heating value (HHV)

The amount of heat generated by the complete combustion, under specified conditions, by a unit volume of a gas or a unit mass of a solid or liquid fuel, in the determination of which the water produced by the combustion of the fuel is assumed to remain as a vapor.

Depending on the determined moisture content of the wood and by using the composition of the fuel for wood biomass (Gaur & B.Reed, june,1995), higher heating value of a given specific wood can be determined.

It has recently been found in a survey of these earlier works that the heat of combustion can be predicted from the ultimate analysis according to the following equation;

$$HHV_d\left(\frac{Kg}{kg}\right) = 0.35C + 1.1783H + 0.1005\,S - 0.1034\,O - 0.0151N - 0.0211Ash$$

Where HHV_d is the high heating value of the sample given in MJ/Kg dry mass and C, H, S, O, N and Ash are the weight % of carbon, hydrogen, sulfur, oxygen, nitrogen and ash respectively [Channiuala, 1992], this equation shows that the element carbon, hydrogen and sulfur increases the heating value where the elements, nitrogen, oxygen and Ash suppress the heating value.

$$HHV_d\left(\frac{Kg}{kg}\right) = 0.35\ x\ 48.00 + 1.1783\ x\ 5.70 + 0.1005\ x\ 0.05 - 0.1034\ x\ 0.5 - 0.0151\ x\ 30 - 0.0211\ x\ 0.75$$

$$HHV_d = 20.51MJ/kg$$

There is also;

$$HHV_d = \frac{HHV}{1-MC} \quad , \quad HHV = HHV_d\ x\ (1 - MC)$$

Where, HHV_d higher heating value of the biomass in bone dry basis

HHV higher heating value determined by the calorimeter, and

MC, moisture content of the biomass in decimal wet mass fraction

Here; moisture content MC of the sample wood log used in the experimental set up is measured by using an oven dryer and MC of the sample wood log found to be 16%.

Finally, the HHV for a wood log with the moisture content of 16%

$$, \quad HHV = HHV_d\ x\ (1 - MC)$$

$$HHV = 20.51\ x\ (1 - 0.16)$$

= 16.82MJ/kg

3.2.3.2 Calculation of LHV

The amount of heat liberated by the complete combustion, under specific condition, by a unit volume of a gas or of a unit mass of a solid or liquid fuel, in the determination of which the water produced by combustion of the fuel is assumed to be completely condensed and its latent and sensible heat made available.

Lower heating value of the wood biomass can be estimated from the measured HHV by subtracting the heat of vaporization of water in the product

The net heating value or LHV is obtained by using the following equation

$$LHV = HHV \quad x\,(1 - MC) - 2.447MC$$

Where LHV, is the net heating value in MJ/kg

MC, is the measured moisture content in wet basis

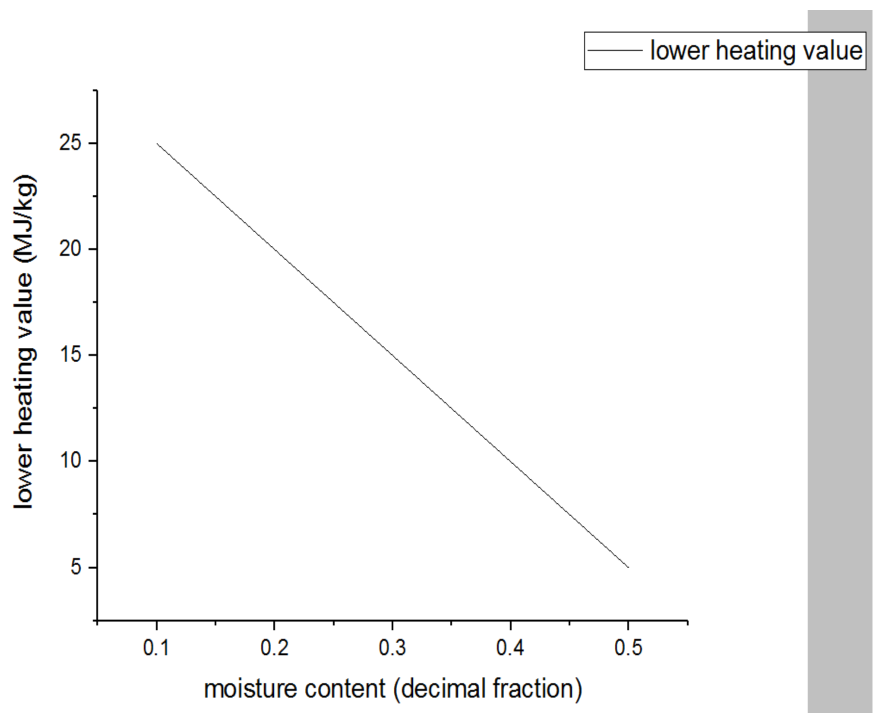
The constant 2.44, the latent heat of vaporization of water in MJ/kg at 25℃

Therefore;

$$LHV = 16.82\ x\ (1 - 0.16) - 2.447\ x\ 0.16$$

$$= 14.35\text{MJ/kg}$$

Plotting of lower heating value versus moisture content of wood biomass.



3.3 Computational fluid dynamics.

This study utilizes the use of Gambit and fluent codes for computational fluid dynamic simulation and analysis. Gambit is a pre-processor used to define the geometry of the model and to create a computational mesh. Boundary conditions for the problem (e.g walls, velocity inlets etc) and continuum type (e.g fluid, solid) are also created using Gambit. Fluent solves the CFD model generated after various initial parameters are set. Fluent may also be used a post processor to visualise and analyse the fluid flow. Colour vectors and contour plots may be created for parameters such as velocity, pressure and tempreture, to assits in giving a visual represention of the fluid.

Also Cmputational fluid dynamics (CFD) is stated as the analysis of systems involving fluid flow, heat transfer, systems that determines the performance of the system itself and etc.by using means of computer based simulations. Aditionally fluent is a CFD package for modeling fluid flow and heat transfer. FLUENT provides CAD/GUI based facility package for generating unstructured meshes to solve flow problems in complex geometries.

All modes of heat transfer (conduction, conviction – forced and natural, radiation, phase change) can be modelled in fluent. The heat transfer caracteristics of mirt stove is also modeled with fluent packages using the considerations; 3D, incompressible and laminar flow. It is also assumed to be steady where the flow variables become independent of time. The appropriate physical flow model, which is available in FLUENT, will then be specified, based on these flow characteristiics of the stove.

3.3.1 Mirt stove the slim version

A decision was made to base the CFD study on the mirt stove. The stove is manufactured from four separate pottery sections including the chimney, the detail of which is shown in the following figure.

Figure 3.5 Mirt stove slim version

3.3.2 The mathematics of CFD

Fluent utilizes an integrated discretized navier stokes solver. This discretizion process generates a set of linear algebraic equation relating the flow field variables (pressure, velocity, turbulence etc) at numerous node points of the mesh. Once reasonable boundary and initial conditions have been defined, it is possible to solve these equations iteratively for the flow field variables at each computational point. It is important to stress due to the iterative nature of the solution process, it will only ever provide approximate numerical solutions to the governing equations.

The accuracy of which is determined by the number of factors. The investment of time and computing power is required to produce valid results, however the exact amount of the investment of both can be reduced with good discretization and careful mnitoring of the solution.

3.3.3 Governing equation

To determine the temperature distribution over the system, the eight equations evolved must be solved simultaneously for the eight unknowns. The stated unknown variables are 8: enthalpy h (or internal energy, u), velocity v, pressure p, viscosity μ, density ρ, and thermal conductivity k. So the velocity and temperature fields are coupled. For the case of incompressible flows density has a known constant value. The fluid flow model for cook stove(injera baking stove) include governing equations such as; conservation of mass (continuity) equation, conservation of momentum (Navier- stokes equation) and conservation of energy (energy equation).

3.3.3.1 First law of thermodynamics

First law of thermodynamics is the law that relates the various forms of energies for system of different types. First law of thermodynamics is simply the expression of the conservation of energy principle. Based on experimental observations, the first law of thermodynamics states that "Energy can be neither created nor destroyed during a process; it can only change forms." The first law of thermodynamics requires all energy within a system to be conserved, even if it changes forms. In cook stoves, combustion transforms stored chemical energy of the fuel into thermal energy. Part of this thermal energy takes on the form of flow energy which is responsible for the buoyant flow of hot combustion gases through the stove and past the surface of the pot. Properly applying the first law to a cook stove leads to a better understanding of the principles governing its operation. The conservation of mass and the conservation of energy principles for open systems or control volumes apply to systems having mass crossing the system boundary or control surface. In addition to the heat transfer and work crossing the system boundaries, mass carries energy with it as it crosses the system boundaries. A cook stove represents an open system since it is characterized by fluid flowing across the boundary of a fixed volume, referred to as a control volume.

The control volume in this case is bounded by the walls of the combustion chamber with the mouth of the stove acting as the inlet and stove wall interface and chimney acting as the outlet, as shown in Figure below.

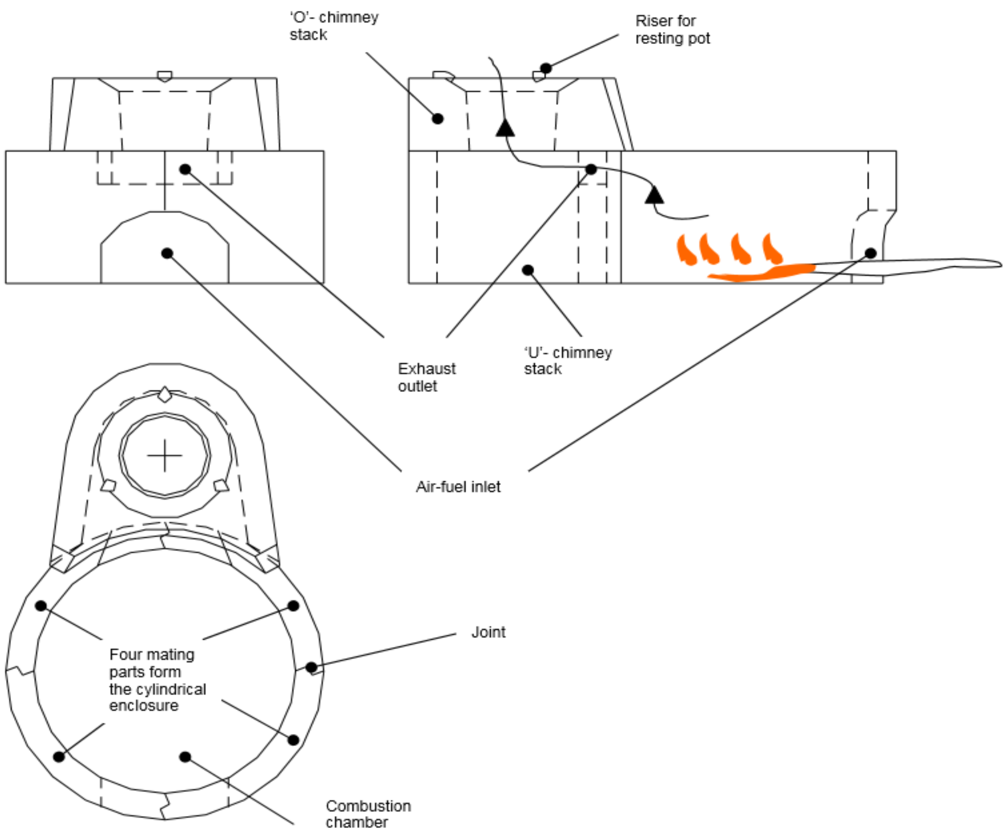


Figure 3.6 Exploit 2D view of mirt stove.

In this case there is a reminder that if the heat transfer efficiency of existing cook stove is to be accurately assessed and improved upon, then all energy involved in the combustion process must be accounted for also. A control volme establishes a finite system boundary to analyse the balance of energy transferred between heat, work and mass flow.

Heat transfer to a system increases the energy of the molecules and thus the internal energy of the system and heat transfer from a system decreases, work transfer to a system increases the energy of the system, and work transfer from a system decreases, and also when mass enters a system, the energy of the system increases becouse mass caries energy with it, like wise when some mass leaves the system, the energy contained within the system decreases.

The rate of mass flow energy transfer to or from a system is represented by equation below

Rate of energy flow = $\dot{m}\ x\ \theta$

Where $\dot{m}$, $is\ bulk\ mass\ flow\ rate\ of\ fluid$

$\theta,\ is\ total\ energy\ of\ a\ flowing\ fluid\ per\ unit\ mass$

The total energy of flowing fluid per unit mass can be broken down further into its fundamental components as;

$$\theta = P\vartheta + (u + ke + Pe)$$

$$\theta = h + ke + Pe$$

Where ; Pv , flow energy of moving fluid

P – pressure diffrence at the location

ϑ – specific volume of the fluid

U – internal energy

Ke – kinetic energy

Pe – potential energy

h – enthalpy

Thermodynamic processes involving control volumes can be considered in two groups: steadyflow processes and unsteady-flow processes. A cook stove is evaluated assuming isobaric steady-flow conditions where bulk mass flow rate remains constant. These assumptions ignore transient effects since these add significant complexity to the energy balance calculations with minimal gains in accuracy. Additionally, most of the time users spend cooking typically when the stove past the “warm up” stage and steady state assumptions are valid. Other simplifying assumptions include constant kinetic and potential energy between the inlet and outlet of the control volume, zero mechanical work, and ideal gas behavior. Based on these assumptions, the energy balance of a cook stove is evaluated through the following relationships;

$$Ei = Eo \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{(3.15)}$$

$$Qi + Wi \sum_i m^{\cdot}\, \theta \;=\; Qo + Wo + \sum_i m^{\cdot} o\, \theta$$

$$Q_i^{\cdot} - Q_o^{\cdot} \;=\; m^{\cdot}\,(\theta_o - \theta_i)$$

$$Q_i^{\cdot} - Q_o^{\cdot} \;=\; m^{\cdot}\,(h_o - h_i)$$

$$Q_i^{\cdot} - Q_o^{\cdot} \;=\; m^{\cdot} cp, avg\,(T_o - T_i) \dots\dots\dots\dots\dots\dots \text{(3.16)}$$

Where, subscripts i and o stands for inlet and outlet variables respectively.

$Q^{\cdot} - rate\ of\ heat\ transfer$

$W - rate\ of\ work\ transfer$

$m^{\cdot} cp\ -\ average\ constant\ pressure\ specific\ heat\ of\ air\ between\ T_i\ and\ T_o$

$T - gas\ tempreture.$

3.3.3.2 Energy equation

The first law of thermodynamics requires that the energy of a system be conserved. This means that the amount of energy entering a system must equal the amount of energy leaving the system. The 3-dimensional energy equation for fluid flow is provided below in equation.

$$\frac{\partial}{\partial t}\left(\rho C_p T\right) + \frac{\partial}{\partial x}\left(\rho \vartheta_x C_p T\right) + \frac{\partial}{\partial y}\left(\rho \vartheta_y C_p T\right) + \frac{\partial}{\partial z}\left(\rho \vartheta_z C_p T\right) \;=\; \frac{\partial}{\partial x}\left(k_{xx}\frac{\partial T}{\partial x}\right) += \frac{\partial}{\partial y}\left(k_{yy}\frac{\partial T}{\partial y}\right) + \frac{\partial}{\partial z}\left(k_{zz}\frac{\partial T}{\partial z}\right) + Q_v \dots\dots\dots\dots\dots\dots \text{(3.17)}$$

3.3.3.3 Laminar flow model

To identify the type of flow inside cylinder reynolds number has been calculated in the next chapter of this paper as a result the flow is laminar. Becouse for fully developed internal flow reynolds number (Re < 2300) is laminar flow. Therefore use of laminar flow is necessary.

A variety of corelation are in use for predicting heat transfer rates in laminar flow. From dimentional analysis, the correlation are usually written in the form,

Nu = f(Re, Pr, …..) where Nu = $\frac{hD}{K}$ $is\ nusselt\ number, f\ is\ some\ of\ function\ and$ … (3.18)

$$\Pr = {\mu gas\ Cpgas}/{Kgas} = {v}/{\alpha} \quad is\ prandtle\ number \ \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (3.19)$$

Here h is heat transfer coffiecient, K is thermal conductivity of the fluid and $C_p$specific heat of fluid at constant pressure. The prandtl number can be written as the ratio of kinematic viscosity ϑ to the thermal diffusive of the fluid α

Efficient heat transfer in laminar flow occurs in the thermal entrance region. A reasonable correlation for the nusselt was provided by sieder and tate.

$$Nu = 1.86\ Re^{1/3}\ Pr^{\frac{1}{3}}(D/L)^{1/3}\ (\frac{\mu b}{\mu_w})^{0.14} \ \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (3.20)$$

As the length of the tube increases, the nusselt number decreases as $L^{1/3}$. This does not, however, imply that the nusselt number approaches zero as the length becomes large. This is becouse the sieder- tate correlation only apllies in the thermal entrance region. In long tubes, where In most of the heat transfer occuurs in the thermally fully- developed region, the nusselt number is nearly a constant indepenndet of any of the above parameters. When the boundary condition at the wall is uniform, Nu = 4.36, But in this case we alrady know the heat flux and a heat transfer cofficient is not needed. Remember that the purpose of using a heat transfer coefficient is to calculate the heat flux between the wall and the fluid. In the case of uniform wall flux, we can use an energy balance directly to infer the way in which the bulk average temperature of the fluid changes with distance along the axial direction.

Notice that the ratio $\frac{\mu b}{\mu w}$ appears in the above laminar flow heat transfer flow heat transfer correlation. We have defined μ as the viscosity of the fluid. The subscript “ bulk” and “ wall” respectively. We know that the bulk tempreture of the fluid will change along the tube. The wall tempreture may be constant, or it may vary along the length of the tube. In all cases, we can use an arithmetic value of the average between the extreme values that occur in the system.

Becouse the exponent and prandtl numbers are raised to the same power in the laminar flow correlation. Therefore, we can write the correlation as;

$$Nu = 1.86\, Re^{1/3}\, Pr^{\frac{1}{3}}(\frac{D}{L})^{\frac{1}{3}}(\frac{\mu b}{\mu_w})^{0.14}$$

3.3.3.4 Turbulence modelling

Due to the bouyant nature of the air flowing through the stove, turbulance will undoubtely exist. To provide an acurate representation of what would occur in reallity and a good platform for analysis accounting for its effects is a very important part of the CFD simulation.

The turbulence modelling capabilities of fluent are very varied, and since the extent of previous CFD work carried out in the field of study is limited, it is hard to determine the best model to utilise. However after taking some advice and reviewing the turbulance models available, it was decided that the use of navier stokes solver with two equation k – ε model would be appropriate. The model is widely used within the CFD community for simulating turbulance and is considered to be the best of the eddy viscosity models due to its good numerical stability.

The two equation, K - ε eddy viscosity turbulance model considers the convective and diffusive transportation of the turbulence itslef. The model is named after its two transported variables K and ε, where K is the turbulent kinetic energy of the flow and ε is the viscous dissipation rate.

In common with all other eddy viscocity models, in the k – ε model, the reynolds stresses are obtained from the boussinesq approximation and the turbulent kinematic viscosity takes the prandtl- kolmogorov form. These are combined to formthe two transport equations which are solved numerically by the computer;

These are given in equation set 2.

- K – transport equation

$$\frac{\partial(U_j^- k)}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\left(\frac{v_l}{\sigma_l} + \frac{v_t}{\sigma_k}\right)\left(\frac{\partial k}{\partial x_j}\right)\right\} + P_k - \varepsilon$$

- ε- transport equation

$$\frac{\partial(U_j^- \varepsilon)}{\partial x_j} = \frac{\partial}{\partial x_j}\left\{\left(\frac{v_l}{\sigma_l} + \frac{v_t}{\sigma_\varepsilon}\right)\left(\frac{\partial \varepsilon}{\partial x_j}\right)\right\} + C_{\varepsilon l}\frac{\varepsilon}{k} P_k - C_{\varepsilon 2}\varepsilon$$

Where $P_k = v_t \frac{\partial U_i^-}{\partial x_j} (\frac{\partial U_i^-}{\partial x_j} + \frac{\partial U_j^-}{\partial x_i})$ is the production rate of turbulent kinetic energy.

Rigorous derivation of the above equations are available from some of the vaious referneces utilised in this study but for the purposes investigating stove design no further understanding is necessary other than to note the limitation of the model. It is normally considered a limitation that the K – ε model is high reynolds number version turbulence model, i.e . is only valid in fully turbulent cases. However for the purpose of this study deemed appropriate, since the nature of the air traveling through a stove since is considered highly turbulent.

3.3.4 Major steps for CFD analysis in FLUENT

This section provides detail about the simulation process from FLUENT ----. There are three major steps involved in the CFD analysis using FLUENT, namely preprocessing, processing and post processing.

Preprocessing is the first step, which includes preparing of the geometrical model for the computation. It consists of creating geometry, mesh generation and set up of boundary zones and specifying physical flow models, fluid properties, boundary conditions, etc. in FLUENT.

Processing is the second step where the solution control and monitoring are carried on along with the actual computaion process in FLUENT.

Post processing is the activity of displaying of graphical results, reporting control variables and plotting of solution files for areas of interest in the flow field.

Inputting of the various parameters

The first step in inputing of the various parameters into fluent is to activate energy equation. Furthermore the definition of a heat source in the heart of the first part of the stove, beneath hot plate(mitad). The size of the heat source determines many characteristics of the fluid's flow; hence it is important that a good approximation for the stoves heat source is made. In addition it is important to review the resulting hot plate and flue gas tempreture give an indication of whether the magnitude of the heat source is sufficient. The K – ε turbulence model is then initialized with the various defoult cofficients and parameters for air being utilized.

The user defined scalar function is utilized to simulate how heat would be transmited through the model. It works in the same way as introducing an ink tracer into a water flow does. Its effects on the composition of the fluid can be defined as negligible, and hence for the purposes of this investigation are considered an appropriate method of monitoring exactly how much heat is transmitted or back drafted into the room the stove is located in.

3.3.4.1 Definition of operating conditions.

the gravitational acceleration is set to the standard 9.8 m/s^2 in the vertical plane. The atmospheric operating tempreture is also defined as an operating condition and for the purposes of this study it is considered as being ambient, i.e. 22^{o}C . however if a specific surrounding air tempreture for a specific stove were determined this parameter would be varied to accommodate. Finally the variable density parameters are also defined, with a specified operating density classified as 0.925 kg/m^3, found by the IUPAC standard correlation [23].

At IUPAC standard tempreture and pressure (0 ^{o}C and 100kpa) dry air has a density of 1.2754kg/m^3.

- At 20 ^{o}C and 101.325kpa, dry air has a density of 1.2041kg/m^3.
- So, at 22 ^{o}C of an ambient air tempreture and 82kpa dry air has a density of 0.925 kg/m^3

with respect to the study area (jimma) with an elevation altitude of 1750m. And also the air prassure at the specified study area is also 82kpa calculated and found from the specific gas constant.

Energy utilization and heat flux analysis of the baking pan.

The total energy is the amount of energy used to cook a certain amount of Injera.it includes both the energy actually utilized in cooking the Injera and the energy lost during baking. The utilized energy is the amount of energy which is actually used in cooking Injera, not including any of the losses during the process of baking. The utilized energy during Injera baking includes the energy required to raise the temperature of the batter to the boiling point of water, plus the energy required to vaporize a portion of water in the batter. The following assumptions are made in order to calculate the amount of utilized energy by a baking pan.

- The average mass of Injera and moisture loss for every single Injera is constant.
- The heat capacity of the batter is nearly equal to the heat capacity of water.
- The difference in weight between the baked Injera and the initial batter is equal to the weight of moisture loss during baking.

By applying the above specified assumptions, the utilized energy can be obtained from the following equation. [26](14. EzanaNegusse, Robert Van Buskirk, and Haile Teclai,"The Effect of Clay and Iron Cooking Plates on Mogogo Efficiency and Energy use: Experimental Results", Energy Research and Training Center, P.O. Box 5285, Asmara, ERITREA)

$$E_{utilized} = m_{batter}C_p\left(T_{boiling} - T_o\right) + h_{fg}(m_{batter} - m_{injera})$$

Where; $E_{utilized} = energy\ utilized\ (J)$,

$m_{batter} = mass\ of\ batter\ (kg)$, 16kg

$m_{injera} = mass\ of\ baked\ injera\ (kg)$, 9.88kg

$C_p = heat\ capacity\ of\ water\ \left(\frac{J}{kg}.K\right)$, 3440J/Kg.K

$T_{boiling} = boiling\ tempreture\ of\ water\ in\ that\ area$ (℃), 100℃

$T_o = room\ tempreture$ (℃), and, 22℃

$h_{fg} = heat\ of\ vaporization\ of\ water\ at\ the\ boiling\ tempreture\ in\ that\ area\ (J/kg)$, $2.26\ x10^6 j/kg$

Here the average mass of Injera and batter during baking using clay baking pan is obtained during experimental investigation.

$$E_{utilized} = 16kg\frac{x3440j}{kg}.k(373 - 293) + 2.26x10^6 j/kg(16 - 9.88)$$

$$E_{utilized} = 18.28\ x10^3 kj$$

Heat flux analysis over the baking pan

The amount of heat flux over the pan surface is calculated as follows;

$$q = E/At$$

Where, E is energy required to bake a single injera, which is 473kJ

A area of the pan surface, 0.4417m^2

t time required to bake a single injera.2.5min

$$q = \frac{473KJ}{0.4417m^2\ x\ 2.5\ x\ 60} = 7.14\text{KW/m}^2$$

3.3.4.2 Building geometry of mirt stove.

The process of defining model with the ansys is fauerly elementary once a suiatably stove geometry has been determined. For these case Geometry of mirt stove is modeled on solid works 2012 then imported to ANSYS FLUENT for further analysis.

General assumptions made in defining the geometry are;

The majority of previous work in the field concerns with method of improving the consumption of fuel wood of stove in general. This study however essentially investigates ways of improving combusion efficiency of the stove as a whole. It is therefore possible to ignore many of the variables related with fuel wood consumption. This can be considered acceptable as fundamentally the primary factors affecting the transferral of smoke through the stoves body are;

- The pressure gradient that exists between the entrance and exhoust of the stove, dependant only on the height of the chimney and the effects of gravitational pull.
- The temperature gradient inflicted by the magnitude of the heat source.
- The resulting effects of turbulance in the stove, equated for by the turbulance model and parameters used.

3.3.4.3 Summary of additional assumption for the model;

I. Within the simulation process only internal cylindirical part of the mirt stove body which is used as combusion chamber and internal part of the chimney is considered.

II. The model is developed for the case where there is no covering pan on the top of the mirt stove.

III. To reduce complexity of mesh the internal cylindrical body and baseplate are considered as one part.

IV. Composition of smoke is assumed the same as air.

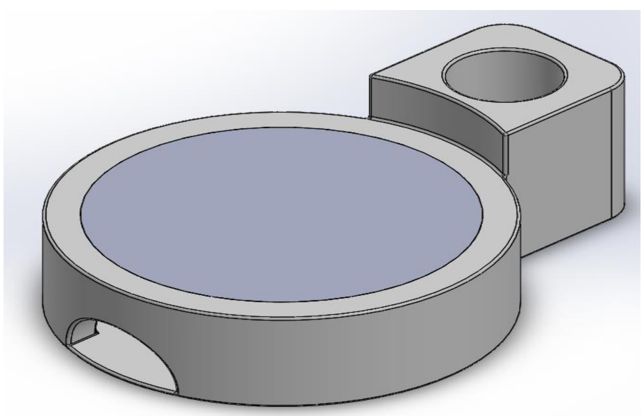


Figure 3.7 3D model of mirt stove

On the above 3D figure of slim version mirt stove the gray colour shows than pan surface contained within the other cylinderical part of the stove.

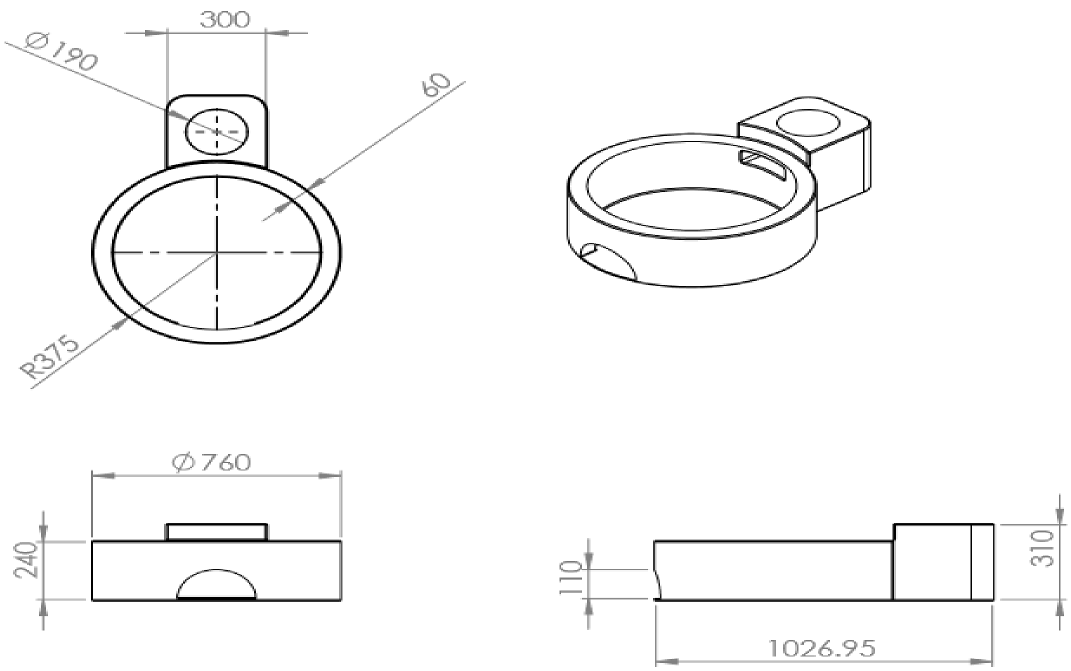


Figure 3.8 detail parts of mirt stove with dimention

3.3.5 Modeling heat transfer in fluent.

In order to model heat transfer in fluent the energy equation should have to be activated. The equation for the energy transport is stated as follows;

$$\nabla[\, v(\rho\epsilon + p)] = \nabla.[\, k_{eff}\,\nabla T - \sum_j h_j J_j \,+\, \tau_{eff} v\,] + s_h \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.21)$$

Where the terms; $\nabla[\, v(\rho\epsilon + p)]$ *stands for convection*

$\nabla.[\, k_{eff}\,\nabla T$ *stands for conduction*

$\sum_j h_j J_j$ *stands for the species diffusion*

$\tau_{eff} v$ *stands for viscous dissipation*

s_h *stands for enthalpy source sink*

The equation for energy E per unit mass is defined as; $h - \frac{p}{\rho} + \frac{v^2}{2}$ where pressure work and kinetic energy are always accounted for compressible flow or when using density- based solver. For pressure based solver they are omitted and can be added through text command.

When fluid moves it carries heat with it and this is called convection heat transfer. Heat transfer can be tightly coupled to fluid flow solution. Energy plus fluid flow is activated means convection computed.

All walls the heat transfer coefficient is computed by turbulent thermal wall function

$$Q = h\left(T_{body} - T_{\infty}\right) = h\,\Delta T \quad where\ h, average\ heat\ transfer\ coefficient$$

The general equation for heat flow is;

$$q = UA\Delta T = \frac{A\Delta T}{R} \quad where\ \ q = rate\ of\ heat\ flow\ in\ watts.$$

Where, U = overall heat transfer coefficient in watts per square meter degree Celsius

A = surface area in square meters

ΔT = temperature difference causing flow in degree Celsius

R = 1/U the overall combined resistance

Generally fluent uses two numerical methods either pressure based or density based solver. In which Both of the equations(solver) solve the governing integral equations for the conservation of mass, momentum, energy and other scalars such as turbulence. Recently both methods have been extended and formulated to solve and operate for a wide range of flow condition beyond their traditional or original intent. In both methods the velocity field is obtained from the momentum equation.

Pressure based segregated algorithm

The pressure based approach was developed for low speed incompressible flows, on the other hand, in the pressure- based approach; the pressure field is extracted by solving a pressure or

Pressure correction equation which is obtained by manipulating continuity and momentum equation

3.3.5.1 Energy equation

The energy equation should have to be activated in order to define and model the energy equation in fluent, radiative heat transfer equation easy to solve with little CPU demand it includes effect of scattering, effect of particles and soot can be included if needed

1. **Definition of materials**

as discussed before the effect of addition of smoke to the model on the composition of the resulting mixture produced is considered negligible, and the nature of this study; to investigate the effect of varying the geometry on the fluid flow through the mirt stove, it is essential possible to only define two materials other than the user defined scalar (acting as a tracer). The properties of which are defined in the following table.

Fluid air

Table3.5 fluid air properties

No	Properties	Value	Air
1	Density	0.9225 kg/m^3	1006.43J/kg.k
2	Specific heat capacity	1006.43J/Kg.k	-
3	Thermal conductivity	0.0242 K[w/(m.k)]	1.789 e^{-5}
4	Thermal expansion coefficient	0.0025Kg/ms	1 e^{-20}
5	Viscosity	1.789 x $10^{-5} kg/ms$	-

As specified above on the table air is the material for the fluid phase occurring in the domain. Even the producer flame gas rising from the fuel bed is specified as air. The property of air which is available from the fluent materials library is used.

a) **Solid clay**

The pan plate or mitad is made up of clay material with a higher thermal conductivity and density compared with concreate material, it can withstand high temperature, here clay material is not included in fluent material data base so introduced to the software by using user defined function. Some important properties of the tile are given in the above table.

Table 3.6 solid clay properties

No	Properties	Value
At a fluid temperature of 300k		
1	Density	1460kg/m^3
2	Specific heat capacity	880J/Kg.k
3	Thermal conductivity	1.3K[w/(m.k)

b) Solid concreate

The cylindrical body and chimney is made up of concreate material which have lower thermal conductivity and lower density when it compared with the clay pan or mitad material, concreate material can withstand high temperatures and corrosion. Here concreate is not included in fluent material data base so introduced to the software by using user defined function. Some important properties of the tile are given in the table below.

Table 3.7 solid concreate properties

No	Properties	Value
At a fluid temperature of 300k		
1	Density	1400kg/m^3
2	Specific heat capacity	800J/Kg.k
3	Thermal conductivity	0.89K[w/(m.k)

c) Wood volatile matter

Table 3.8 wood volatile matter.

No	Properties	Value

At a fluid temperature of 300k		
1	Density	1kg/m^3
2	Specific heat capacity	1500J/Kg.k
3	Thermal conductivity	0.0454w/(m.k)
4	Viscosity	1.72$e^{-05}kg/mJ$

2. **The solution process**

The model is initialized from the condition of the combustion chamber.

3.3.5.2Mesh

Reviewing the solutions produced prior to the iteration process occurring is very important. The definition of this mesh plays a large part in their accuracy and hence many needs to be refined. A good solution is obtained if good meshes for the models are generated. The accuracy of the solutions depends on the sizes of the meshes.

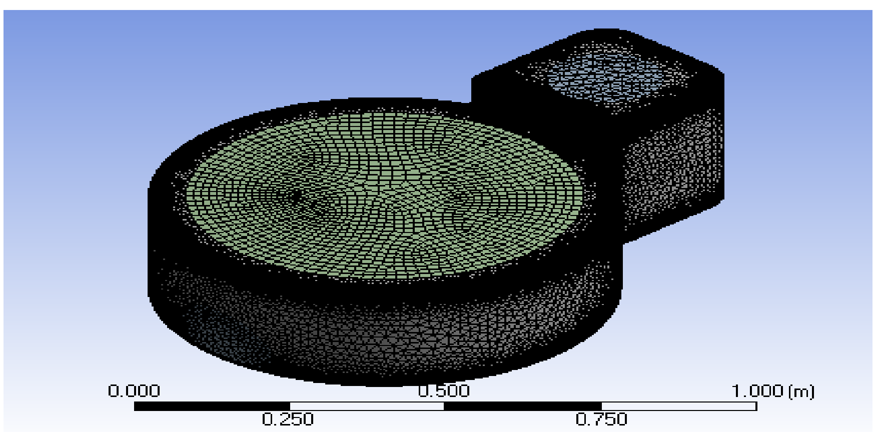


Figure 3.9 Mesh and named selection used as boundary condition

The mesh information of the three zones or parts is given with the following table.

Table 3.9 Mesh information for FFF

Domain	Nodes	Elements
fluid_zone	254498	1327290
solid_body	516226	2655562
solid_pan	7796	33458
All Domains	778520	4016310

Boundary condition

Different boundary conditions used in this domain are the boundary condition at the inlet of the stove, boundary condition at the walls of the stove as well as the boundary condition at the outlet of the stove is also considered

3. Boundary condition at the stove inlet

It's the part where air inters to combustion chamber, the flow property of the entering air is calculated from experimental result and also the following assumptions are taken for this velocity inlet boundary condition.

So the following considerations are taken;

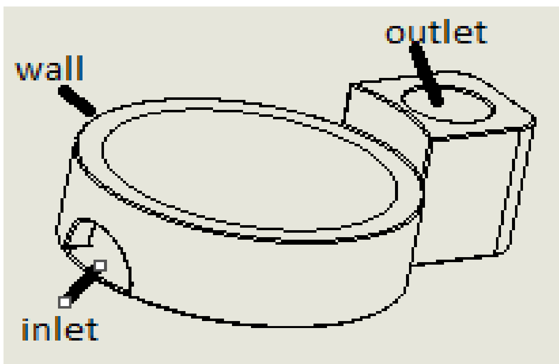
- Stagnation pressure is ambient pressure
- Neglect the viscous losses due to acceleration of fluid from the surrounding of the stove inlet
- The temperature at stove inlet is assumed to be the ambient temperature at the specific location which is $22^0C \;\; or \; 295k$ [25]
- Fluid velocity at the inlet is 0.55m/s calculated and found by using the following equation.

It has been known that;

Density: ρ = (353.09)/(T)kg/m^3Gas Properties [26]

T=295k, ρ=0.982kg/m^3

- Volumetric flow of gases=(Bulk flow of gases)/(ρ)
  =(67kg/hr)/0.41kg/m^3= 163.4m^3/hr
- Velocity of gases= (Volumetric flow of gases)/(area)
- Area of combustion chamber=0.0534m^2
- Velocity of wood-volatile =(163.4m^3/hr)/(0.0534m^2)
  =2905.8m/hr = 0.557m/s



Using the flow velocity of air at this position the Reynolds number for fully developed internal flow through circular pipe will be calculated to identify the nature of the fluid flow into the combustion chamber;

$$R_e = \frac{\rho gas\; v_{inlet}\; d}{\mu_{gas}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (3.22)$$

Where $\rho - density\ of\ the\ fluid, \frac{kg}{m^3}$

V – velocity of fluid through cylinder, m/s

d- diameter of the circular part, in m

$\mu -$ absolute viscosity, 1atm and 237k, kg/m. s

Therefore, depending up on the above given values and by using the stated equation the calculated value of Reynolds number will be;

Re = 1047 which indicates that the flow is laminar

The boundary condition is considered as pressure outlet and pressure value will be extrapolated from the flow in the combustion chamber (interior). And also all other flow quantities are extrapolated from the interior so the following considerations are taken;

- Static pressure is at ambient pressure
- Velocity outlet will be the same as the velocity measured
- Fluid temperature extrapolated from the upstream value

Flow inside the wall of the combustion chamber is surrounded by the clay body which is considered as solid wall. The thermal boundary condition at the wall of the stove body considers the following conditions;

- Heat flux, temperature, convective heat transfer, external radiation and combined external radiation and external convective heat transfer but for this simulation process temperature at wall is specified depending on the average temperature taken from the experimental data, which is 379k
- There is no slip condition
- Heat exchange on the bottom part of the stove is negligible, but considerations are taken because there is conduction heat loss to the base plate of the stove.

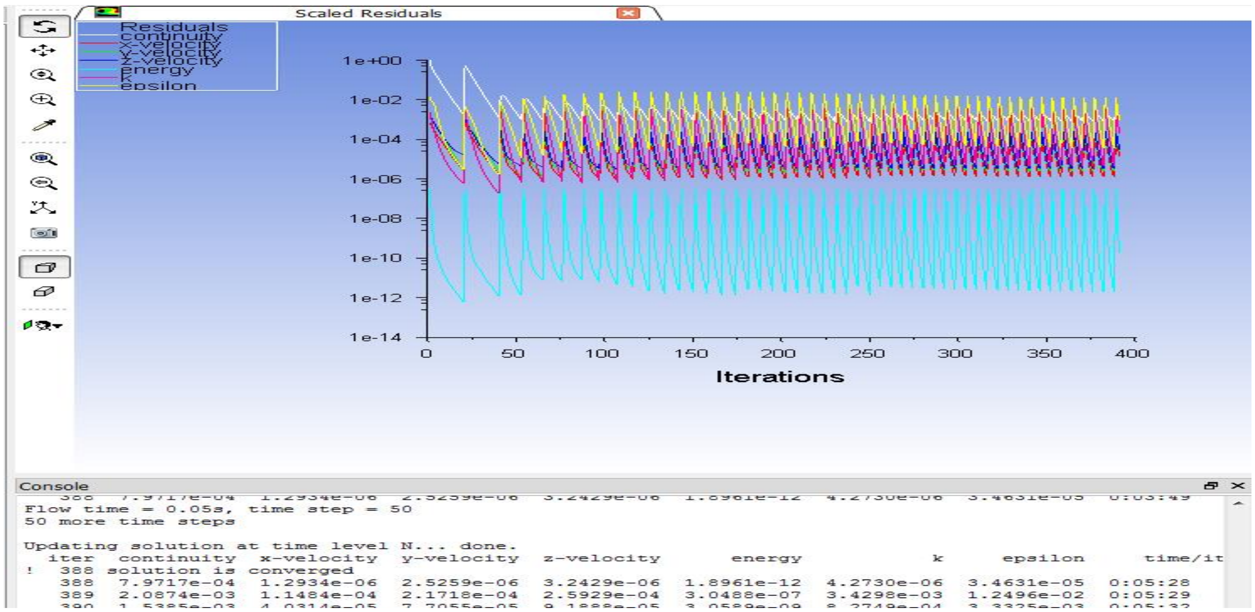
Generally, the main boundary conditions considered within the system is presented within the following table generated after the fluent CFD analysis is completed.

Table 3.10 Boundary physics for FFF

Domain	Boundaries	
fluid_zone	**Boundary - inlet**	
	Type	VELOCITY-INLET
	Boundary - outlet	
	Type	PRESSURE-OUTLET
	Boundary - wall fluid_zone solid_body shadow	
	Type	WALL
	Boundary - wall fluid_zone solid_pan shadow	
	Type	WALL
solid_body	**Boundary - bottom_wall**	
	Type	WALL
	Boundary - interior solid_body solid_pan solid_body	
	Type	INTERFACE
	Boundary - outside_body	
	Type	WALL
	Boundary - wall fluid_zone solid_body	
	Type	WALL
solid_pan	**Boundary - interior solid_body solid_pan solid_pan**	
	Type	INTERFACE
	Boundary - sarface_wall	
	Type	WALL
	Boundary - wall fluid_zone solid_pan	
	Type	WALL

Computing the solution

The final step in the ansys CFD analysis of the fluid flow in mirt stove is initializing the solution and performing calculation by setting number of iterations and initial guess for starting the solution flow field. So the convergence history of the process is displayed on the window during iteration of the given parameters.



5. **Examining the result**

As already mentioned above the output results are examined to review the solution and to extract useful data’s that contains detail information about the system. The output result can be reviewed through numerical report or graphical display. In graphical display the overall flow pattern and determination of key flow features can be examined while in numerical reporting necessary integral quantities can be computed at boundaries of the flow domain.

3.3.6 Result of CFD analysis

Heat transfer and fluid flow simulation on ansys fluent assists the developments of a simple model which can be used to predict the performance of a given stove. The result of the analysis in ansys FLUENT can be shown by using graphical displays of different parameters as well as numerical data output of the system in general.

3.3.6.1 Graphical display and numerical output

The output illustrated below is the graphical display of the mirt stove.

1. Graphical display of temperature contour on the overall body of mirt stove.

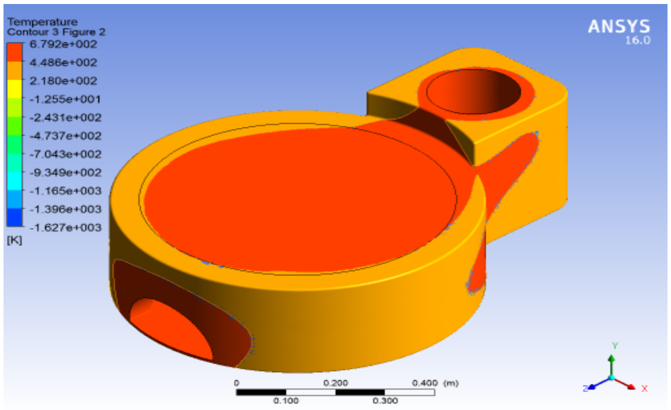


Figure 3.10 temperature contour for the solid body

2. Graphical display for temperature contour over the fluid body

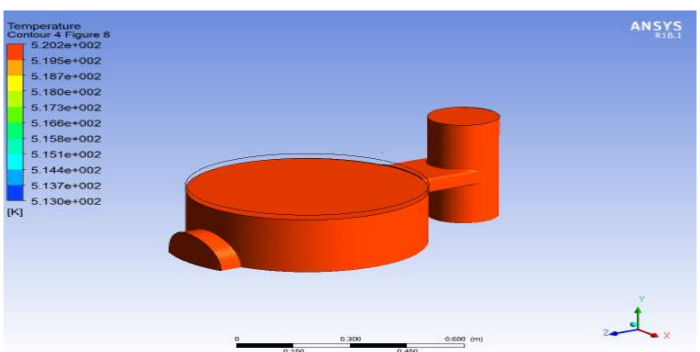


Figure 3.11 temperature contour for the solid body

3. Graphical display for velocity profile over mirt stove

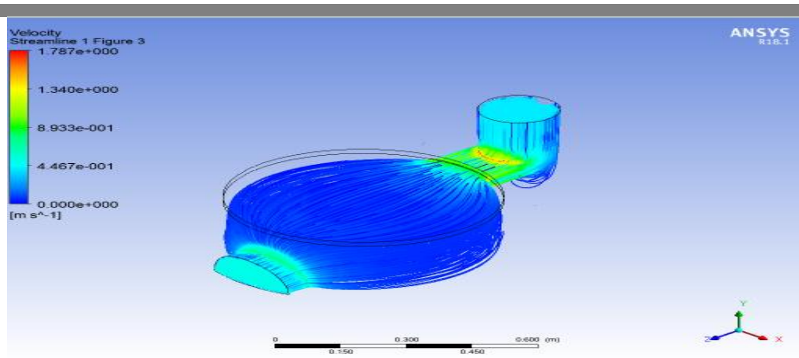


Figure 3.12 velocity profile of a fluid body

4. Temperature stream line showing the distribution of temperature over the concreate solid body.

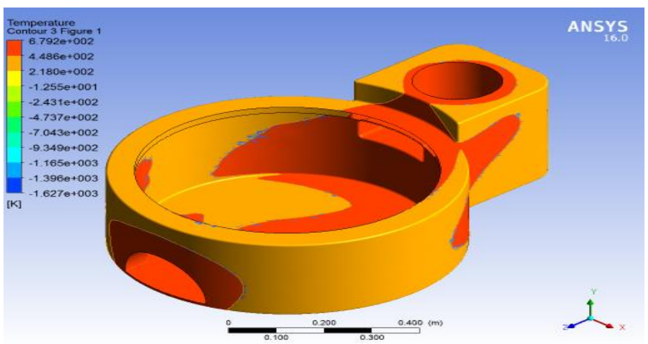


Figure 3.13 temperature contour over the solid body

1. **Numerical output for CFD analysis**

At the end of the iteration process(analysis) or after convergence is reached on fluent ansys output quantitative results like velocity at the outlet, temperature distribution over the overall system, heat transfer rate over the system are taken for further evaluation of design parameters used in the system. On the following table detail information or report about field variables at the inlet, outlet and on the system wall is illustrated as follows. The field variables used are velocity at the inlet and outlet, temperature through inlet, wall and outlet as well as heat transfer rate of the system through the inlet to outlet.

Table 3.11 numerical output summary of the CFD analysis

Field variables	***Field variable***	***Parameters***

	position	
Velocity magnitude	Inlet	0.5m/s
	Outlet	0.65014m/s
Total temperature	Inlet	295K
	Outlet	420K
	Surface wall	342K
Total heat transfer	Inlet	3805.49W
	Outlet	-2627.47W

3.4 Thermal efficiency of the system

By using fluent Ansys simulation software energy model and fluid model of the biomass Injera baking stove is simulated to compute the heat transfer rate in the given domain. And finally the thermal efficiency of the stove can be calculated by using the following equation.

$$\eta_{th} = \frac{Q_{utilized}}{E_{energy\ in\ fuel}}\ x\ 100$$

$where\ Q_{utilized}$; heat utilized $\left(\text{heat transfered to the } \frac{\text{pan}}{\text{plate}} \text{bottom}\right)$ by realizing the nmerical output data given on table. let assume that heat transfer rate on the outlet is utilized on the bottom of pan surface with the value of 2627.47W. Here, depending on the energy analysis done on the chapter 4 of this paper total heat loss by convection and radiation 25%.

Therefore by considering the heat loss due to convection and radiation within the system; $Q_{utilized}$ will be 1738w

Energy in the fuel = energy consumed/ average time to bake Injera

$$Energy_{in\ fuel}\ \frac{LHV\ x\ m_{wood}}{t_{bake}}$$

Lower heating value of biomass wood(dry basis) LHV = 1.428 x $10^7 J/kg$

Mass of wood (m_{wood}) = 1.462Kg

$$Energy_{in\ fuel}\ \frac{LHV\ x\ m_{wood}}{t_{bake}}$$

$$= 4.639\ x\ 10^3 w$$

$$\eta_{th} = \frac{1738}{4639}\ x\ 100$$

= 34%

Chapter 4. Analytical investigation on mirt stove

4.1 Introduction

The thermal and combustion efficiency of the existing stove can be improved if and only if the heat transfer efficiency of the existing stove is assessed. In order to increase the heat, transfer to the pan, the overall heat transfer coefficient h, area under the combustion chamber which is exposed to the flame and flue gases, flame temperature T needs to be increased. From the back ground of heat transfer the overall heat transfer coefficient h, is mainly composed of convective and radiative heat transfer coefficients.

The given equations that govern the behavior of cook stove are rooted in thermodynamics, further explained using principles of heat transfer, and influenced by various stove geometries.

The major modes of heat transfer that plays a major role in the stove performance as a whole are;

- Convective heat transfer
- Radiative heat transfer
- Conduction heat transfer
- The energy wasted.

Within this chapter the detail discussion of steady state heat transfer model of natural draft for biomass cook stove which is known as mirt stove will be included.

And also all modes of heat transfer such as conduction, convection and radiation is modeled depending on surface temperature measured during experimental analysis of the stove. As well the temperature and velocity profile, location and the magnitude of losses' examined and heat transfer contributions through various modes are also discussed in brief.

Additionally, energy balance is analyzed and the result in gain or loss will be discussed in detail.

4.2 Heat transfer and energy balance

From the thermodynamics background thermal energy is directly related with the temperature of the matter. Heat transfer can be described as the study of the exchange of thermal energy through a body or between bodies which occurs when there is a temperature difference between them. When two bodies are at different temperatures, thermal energy will be transferred from the one with higher temperature to the one with lower temperature. Thou heat is always a transfer from the hot or higher temperature to the cold or to the lower temperature. Q is the typical symbol of heat which is expressed in joules (J) which is the SI unit. Again the rate of heat transfer is measured in watts (W) which is equal with joule per second (J/s) and can be donated by q, the heat flux or the rate of heat transfer per unit area is also one of the important parameter in heat transfer and it is measured in watts per area (W/m^2), and uses the symbol φ as a representation.

Generally, there are three mechanisms where heat is transfers through a physical body, and these are conduction, convection and radiation. The energy exchange between any physical bodies occurs through one of the mentioned heat transfer mechanism or in combination of them. Conduction is the transfer of heat through solids or stationary fluids. Convection uses the movement of fluids to transfer heat. And radiation doesn't require a medium for transferring heat; radiation uses the electromagnetic radiation emitted by an object for exchanging heat.

When the above modes of heat transfer mechanisms are takes place there will be gain and loss in energy within the specified system. So gains are associated with heat transfer to a pan and losses are related or associated with heat transfer into a body or out to the ambient (atmosphere). Through this process conduction heat transfer is negligible because they are accounted for in the change of energy of the stove, but convection and radiation losses can be calculated for both the stove and the pan based on their surface temperature during the combustion process. In order to improve the thermal efficiency of the stove or to increase the heat transfer to the pan or mitad heat losses in different forms from different areas of a stove should have to be minimized.

4.2.1 Conduction heat transfer

Conductive heat transfer occurs through the floor of the stove to the ground, through the body of the stove to the surrounding, and through the thickness of the mitad (pan). There is zero energy gains associated with the conduction heat transfer mode to the pan (mitad). Here larger the mass and specific heat of an object , the more energy it can store for a given change in temperature , because of this a massive stove warms up slowly while a lightweight stoves warms up rapidly.

The rate of steady state conduction heat transfer is defined by the following equation

$$Q_{conduction} = \frac{k * A * \Delta T}{L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.1)$$

Where k, is thermal conductivity

A, cross sectional area of the object

ΔT, tempreture difference

L, object thickness

Conduction through the stove floor to the ground is the only instance where the heat from the fuel is transferred to the stove via stationary medium the charcoal (ash) bed.

Conduction through the stove walls does not directly contribute to the energy balance since it affects contribution from radiation and convection as discussed later. Conduction heat loss to the base plate is also neglected or does not consider because of the finite nature of the thickness of the base plate.

4.2.2 Convection heat transfer

Hot combustion gases interact with two separate surfaces; the inner surface of the stove (losses) and the outer surface of the plate (mitad) gains. In convictive heat transfer mode, the heated fluid is constantly replaced by cooler fluid, the rate of heat transfer is enhanced. Convection coefficient, h is the measure of how effectively a fluid transfer heat by convection and it is measured in W/m^2k and is determined by factors such as the fluid density, viscocity, and velocity of the fluid.

Convection is modeled by newton's law of cooling

$$Q = hA\ (T_s - T_\infty)$$

Where; Q; heat transfer

h; convective heat transfer coefficient

A ; surface area

T_s; Surface temperature

T_∞ ; Ambient fluid (air) temperature

$$m_{flow\ rate} = 3.129\ x\ 10^{-3}\ kg/s$$

$T_{gas} = 605k$ $flue\ gas\ tempreture$ at the outlet

$T_{pan} = 449k$ $average\ tempreture\ on\ the\ mitad\ surface$

$R_{universal} = 8.314\frac{J}{K}.mol$ $universal\ gas\ constant$

$m_{mass\ of\ air} = \frac{28.97gm}{mol}$ $molecular\ mass\ of\ air$

$P_{atm} = 76kpa$

$D_{stack} = 315mm$ Diameter of the combustion chamber

$R_{air} = \frac{R_{universal}}{m_{air}}$ $R_{air} = \frac{289.997J}{kg}.k$

$\rho_{gas} = \frac{P_{atm}}{R_{air}T_{gas}}$ $\rho_{gas} = \frac{1.01325\ x\ 10^5 pa}{\frac{289.997J}{kg}.k\ x\ 605k} = 0.577kg/m^3$

$A_{stack} = \frac{\pi D^2 stack}{4}$ $A_{stack} = \frac{\pi 315^2}{4} = 7.79\ x\ 10^{-3}m^2$

$V_{gas\ stack} = \frac{m_{flow\ rate\ stove}}{\rho_{gas}A_{stack}}$ $V_{gas\ stack} = \frac{28.97gm/mol}{0.577\ x\ 9.49x10^{-3}m^2} = 0.629m/s$

Bernoulis equation basic form

$$\frac{P1}{\rho} + \frac{1}{2}V^2 + gz_1 = \frac{p2}{\rho} + \frac{1}{2}V^2 + gz^2$$

The Bournolis equation reduced to fit boundary condition at the stove inlet

$P_{gauge} = P_1 - P_2 = \rho\frac{1}{2}(V_2^2 - V_1^2)$ Where $V_1 = 0$

And the gauge pressure at the stove inlet will be calculated by using the following equation

$$P_{gauge} = \rho\frac{1}{2}(V_{gas\ stack}^2) = 0.079pa$$

Nominal absolute viscosity of air at 1atm and T = 273K

$\mu_0 = \frac{1.71\, x\, ^{-5} kg}{m}.s$ and $\mu_{gas} = \mu_0 \left(\frac{T_{gas}}{T_o}\right)^{0.7} = 2.54\, x\, \frac{10^{-5} kg}{m}.s$

Reynolds number approximation for fully developed internal flow through circular pipe is given in the following equation;

$$Re_{stack} = \frac{\rho_{gas}\, x\, v_{gas}\, x\, D_{stack}}{\mu_{gas}} \quad , \quad \frac{\frac{0.577 kg}{m^3}\, x \frac{0.639 m}{s}\, x\, 315 mm}{2.54 \frac{x 10^{-5} kg}{m}.s}$$

$$Re_{stack} = 1.5944\, x\, 10^3$$

For the case of fully developed internal flow Reynolds number less than 2300 (Re < 2300) are considered as laminar flow.

1. **Convection heat loss from gas in combustion chamber to wall of the inner cylindrical part of the stove.**

$$\boldsymbol{Q_{conv.iner\ wall} = h_{iner\ wall} A_{iner\ wall} \left(T_{gas} - T_{inner\ wall}\right)} \text{ ……………(4.2)}$$

Circular diameter of the combustion chamber	$D_{combusion\ chamber} = 315mm$
Effective length of the chamber	$L_{chamber} = 240mm$
Effective chamber surface area	321536mm^2
Average temperature at the internal wall of the chamber	T = 376K

The friction factor between gases and the walls of combustion chamber can be calculated by assuming fully developed internal flow contained by smooth walls and by using the following friction factor equation;

$$f = \frac{64}{Re_{stack}} = 0.040$$

And the Pradntl number can be calculated by using the ratio of thermal dissipation conduction

$$\Pr = \frac{\mu_{gas}\, cp_{gas}}{Kgas} = \frac{2.54\ x\ 1006.43}{10.5\ x\ 10^{-2}} = 2.81$$

The effect of wall roughness and laminar flow conditions ($Re_D > 2300$) may be considered by using the Gnielinski correlation: nusselt number represents a dimensionless temperature gradient at the surface.

$$Nu = 1.86\, Re^{1/3}\, Pr^{\frac{1}{3}} (D/L)^{1/3} \left(\frac{\mu b}{\mu_w}\right)^{0.14} = 7.57$$

Convection coefficient through the inner wall of the chamber;

$$h_{iner\ wall\ chamber} = \frac{Nu\ Kgas}{D} = \frac{7.57\ x\ 10.5\ x\ 10^{-2}}{0.35} = 7.22\,\frac{w}{km^2}$$

Finally, the convection heat loss from the chamber through the internal walls of the combustion chamber will be calculated using the following equation;

$$Q_{conv.iner\ wall} = h_{iner\ wall}\, A_{iner\ wall}\, (T_{gas} - T_{inner\ wall}) \qquad (4.3)$$

$$= 7.22\ x\ 0.0779\ x\ (605k - 376k)$$

= 128.79 W

2. Convection heat transfer from combustion chamber to the bottom of the plate.

$$Q_{conv.pan} = h_{conv\ pan}\, A_{pan}\, (T_{gas} - T_{conv\ pan}) \qquad (4.4)$$

By assuming the space created between the combustion chamber and the bottom of the pan as a it behaves like two parallel plates.

$$D_{pan} = 375mm$$

$$A_{pan\ bottom} = \frac{d_{pan}^2}{4}\,\pi = 0.4417m^2$$

$$L_{pan\ gap} = 26mm \quad height\ of\ air\ gap\ between\ the\ cobusion\ chamber\ and\ pan$$

$$A_{pan\ bottom} = \pi d_{pan} L_{pan\ gap} = 0.053m^2$$

Estimated value of gas velocity flowing through pan gap area.

$$V_{gas\ pan\ gap} = \frac{m_{stove}}{\rho_{gas}\, A_{pan\ gap}} = \frac{28.97g/mol}{0.577kg/m^3\ x\ 0.053m^2}$$

= 0.67 m/s

The hydraulic diameter definition between two parallel plates $D_h = 2h_{pan\ gap} = 52mm$

$$Re_{pan\ gap} = \frac{\rho_{gas}\, V_{gas\ pan\ gap} D_h}{\mu_{gas}} = \frac{\frac{0.577kg}{m^3}\ x\ 0.96\frac{m}{s}\ x\ 0.052m}{2.54\ x\frac{10^{-5}kg}{m}.s} = 1.13\ x\ 10^2$$

The value of Reynolds number specified within the value states that the flow through pan gap is that less turbulent than in stack.

$$C_{p-gas} = 0.624\ x\frac{10^3 J}{kg}.k \quad specific\ heat\ capacity\ of\ air\ depending\ on\ the\ average\ gas$$

$tempreture.$

$K_{gas} = 10.5\ x\ 10^{-2}\frac{w}{k}.m$ Thermal conductivity of air depending on gas tempreture.

Prandtle number or the ratio of thermal dissipation conduction.

$$p_r = \frac{\mu_{gas}\, C_{p-gas}}{K_{gas}} = \frac{2.54\ x\frac{10^{-5}kg}{m}.s\ \ x\ 0.624\ x\frac{10^3 J}{kg}.k}{10.5\ x\ 10^{-2}\frac{w}{k}.m}$$

$$p_r = 0.15$$

Also the stagnation nusselt number for fully developed internal flow will be calculated by using the following equation.

$$Nu_D = 1.86\left(\frac{Re_D Pr}{L/_D}\right)^{\frac{1}{3}}\left(\frac{\mu}{\mu_s}\right)^{0.14} = 1.86\left(\frac{261\ x\ 0.15}{\frac{0.026}{0.650}}\right)^{\frac{1}{3}}(0.814)^{0.14}$$

$$Nu_D = 17.5$$

Generally, the theoretical convective coefficient for isothermal non combusting impinging flow upon the pan(mitad) bottom will be analyzed by using the following equation.

$$h_{conv\ pan} = \frac{Nu_{gas}\, K_{gas}}{d_{pan}} = \frac{4.9w}{k}.m^2$$

Accounting for the combustion and therefore flame radiation can increase the magnitude of the convective heat transfer coefficient anywhere from 2.3x for low flame and 3.4x for higher flame(Viskanta.R); so the convective heat transfer on the bottom of the pan will be;

$$h_{conv\ pan\ low\ flame} = 2.3\ x\ 4.9 = \frac{11.27w}{k}.m^2$$

$$h_{conv\ pan\ high\ flame} = 3.4\ x\ 4.9 = \frac{16.66w}{k}.m^2$$

By assuming the convictive heat transfer on the bottom of the pan as a high flame;

$$h_{conv\ pan} = \frac{16.66w}{k}.m^2$$

The surface area of the pan(A_{pan}) 0.33m^2 and average temperature of the plate(pan) is 449k then the heat loss to the bottom pan will be calculated by;

$$\boldsymbol{Q}_{conv\ pan\ bottom} = h_{conv\ pan} A_{pan}\left(T_{gas} - T_{pan}\right) = 857.6w$$

3. **Total convection heat transfer contribution.**

$$\boldsymbol{Q}_{conv\ total} = \boldsymbol{Q}_{conv\ comb\ chamber} + \boldsymbol{Q}_{conv\ pan\ bottom} = 986.4\text{w}$$

The conviction heat loss from the combustion chamber through the inner wall of the stove will be;

$$\boldsymbol{Q}_{\boldsymbol{conv\ loss}} = \boldsymbol{Q}_{\boldsymbol{conv\ comb\ chamber}} = 128.8w$$

The convective heat gain from the combustion chamber through the bottom of the baking pan will be;

$$\boldsymbol{Q}_{\boldsymbol{conv\ gain}} = \boldsymbol{Q}_{\boldsymbol{conv\ pan\ bottom}} = 857.6w$$

4.2.3 Heat transfer by radiation

The term radiation covers a vast array of phenomena that involve energy transport in the form of waves. Above the absolute temperature of zero K, all substances emit electromagnetic radiation. In contrast with conduction and convection, heat transfer by radiation does not require the presence of a material medium.

Radiation is modeled by the Stefan-Boltzmann law,

$$Q = \varepsilon\sigma T_s^4 - \alpha\sigma T_\infty^4 \quad \text{……………………………………….. ……. …….. ………(4.5)}$$

Where Q heat transfer

σ *steffen boltzman constant*

α *thermal absorptivity*

ε *emmisitivity*

T_s *surface tempreture*

T_∞ *ambient fluid(air)tempreture*

$\boldsymbol{T}_{base\ plate} = 549k$

$T_{inner\ cylinder} = 695.7k$

$\varepsilon_{flame} = 0.72$ *estimated emmisitivity value of diffusion flame from litterature*

$\varepsilon_{wood} = 0.85$ *estimated emmisitivity value of burning wood from literature*

$\varepsilon_{clay} = 0.75 = \varepsilon_{cylinder}$ *estimated emmisitivity of ceramic pan and cylinder.*

$$A_{ceramic\ pan} = \frac{\pi d^2}{4} = 0.33m^2$$

$$A_{cylinderical\ chamber} = \frac{\pi d^2}{4}$$

$\sigma = 5.67\ x \frac{10^{-8} w}{m^2 k^4}$ $\quad$ $stefan\ boltzman\ constant$

$$Q_{radiation\ loss\ to\ wall\ of\ comb\ chamber} = \frac{\sigma_{stefen} A_{cylinder} (T^4_{cylinder} - T^4_{average})}{\frac{1}{\varepsilon} + \frac{1-\varepsilon}{\varepsilon} \frac{R\ innner\ cylinder}{R\ outer\ cylinder}} \quad \ldots\ldots\ldots\ldots (4.6)$$

The average steady state surface temperature of the flame and wood

$$T_{average} = 0.6T_{flame} + 0.4T_{wood} = 0.6(605.5) + 0.4(420.5) = 531.5k$$

$R_{inner\ cylinder} = 325mm$

$R_{outer\ cylinder} = 327.5mm$

$A_{inner\ cylinder} = 0.336m^2$

Area weighted average emissivity for this region (i.e for the cylindrical stove and pan)

$$\epsilon = \frac{\epsilon_{cylinderical}\, d_{cylinderical} + \epsilon_{pan} d_{pan}}{d_{cylinderical} + d_{pan}}$$

$$= \frac{0.75\ (0.655) + 0.75(0.650)}{0.650 + 0.650}$$

= 0.752

Finally, the steady state radiative heat loss to the inner cylindrical body of the stove will be;

$$Q_{radiation\ loss\ to\ wall\ of\ comb\ chamber} = \frac{\sigma_{stefen} A_{cylinder} (T^4_{cylinder} - T^4_{average})}{\frac{1}{\varepsilon} + \frac{1-\varepsilon}{\varepsilon} \frac{R\ innner\ cylinder}{R\ outer\ cylinder}} \quad \ldots\ldots\ldots\ldots (4.7)$$

$$= \frac{5.67\ x \frac{10^{-8} w}{m^2 k^4}\ x\ 0.336m^2\ (695.7k^4_{cylinder} - 531.5^4_{average})}{\frac{1}{0.752} + \frac{1-0.752}{0.752}\ (\frac{0.325}{0.327})}$$

= 329.2W

1. **Radiation heat transfer from flame to pan(mitad) bottom.**

The total radiation heat transfers from the flame in the combustion chamber supplied to pan (mitad) bottom. By assuming the pan as a black body with $\varepsilon = \alpha = 1,$ radiation is diffusive, or directionally independent) , and reflective of flame is negligible. The heat loss from the flame to the bottom of the plate is given by the following equation;

$$Q_{radiation\ loss\ to\ plate\ bottom} = A_{flame}\, F_{flame}\, \sigma_{stefen}\, \epsilon_{flame}\, (T_{flame}^4 - T_{pan}^4)$$

$$where\ T_{flame}^4 = 705k \quad average\ tempreture\ of\ the\ emitting\ area$$

$$where\ T_{pan}^4 = 549k \quad average\ tempreture\ of\ bottom\ plate\ surface$$

$$R_{flame} = 325mm \quad effective\ radious\ of\ emitting\ the\ flame$$

$$R_{plate} = 327mm \quad effective\ radious\ of\ the\ plate\ bottom$$

$$L_{flame} = 26mm \quad separation\ distance\ between\ the\ two\ effective\ areas$$

$A_{flmae} = \pi R^2 = 0.331m^2$ Effective emitting flame area

$A_{plate} = \pi R^2 = 0.349m^2$ Effective area of the plate bottom

Variable simplification for view factor calculation

$$S_{flame\ view} = 1 + \frac{1 + (\frac{R_{plate}}{L_{flame}})^2}{(\frac{R_{flame}}{L_{flame}})^2} = 2.02$$

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

$$= 0.86$$

Finally, the radiation heat transferred to the plate surface will be given by using the following radiative heat transfer equation;

$$Q_{radiation\ loss\ to\ plate\ bottom} = A_{flame}\, F_{flame}\, \sigma_{stefen}\, \epsilon_{flame}(T_{flame}^4 - T_{pan}^4)$$

= 154W

2. **Total radiation heat transfer contribution;**

$Q_{Total} = Q_{rad\ flame\ to\ plate} + Q_{rad\ loss\ to\ inner\ cylinder\ body}$ = 483.2W

Total convection heat gain $\boldsymbol{Q_{conv\ gain}} = 857.6w$

Total convection heat lost to a system $\boldsymbol{Q_{conv\ loss}} = 128.8w$

$\boldsymbol{Q_{utilized}} = \boldsymbol{Q_{rad\ gain}} + \boldsymbol{Q_{conv\ gain}} = 1501.6w$

$\boldsymbol{Q_{lost}} = \boldsymbol{Q_{rad\ lost}} + \boldsymbol{Q_{conv\ lost}} = \mathbf{458}w$

From total heat generated by convection and radiation 75.52% is utilized heat while 25.58% is heat loss.

4.3 Thermal efficiency

Thermal efficiency is calculated per the sum of convective and radiative heat transfer into all regions of the pot divided by the firepower.

$$\eta = \frac{Q_{rad\ gain} + Q_{conv\ gain}}{Energy_{in\ fuel}}\ x\ 100$$

$$\eta = \frac{1011.6}{4639}\ x\ 100$$

= 25%

Chapter 5. Environmental impact assessment of mirt stove within the study area.

5.1 Introduction and Description of the Study Area

Jimma zone is found in Southwest Ethiopia. It is located at 7°, 33 N and 36°, 57' E at an altitude of 1710 meter above sea level. The mean annual temperature of the town ranges around 26.80c to 11.40c. The relative humidity's are 91.4% and 39.92%, respectively. The mean annual rainfall of the study area is 1500mm and the soils of the study area are dominated by Nitisol. (BPEDORS,

2000). Physical and Socio-Economical Profile of 180 District of Oromia Region, Ethiopia).

Furthermore, Fuel consumption of other biomass fuels besides fuel wood does not show significant differences between both groups. Only fuel wood as the most important fuel was analyzed quantitatively. Charcoal is not used to prepare staple food; it is only used in small quantities for heating beverages in the study area.

The methodology followed in this research is based on the objectives formulated above and the full detailed flow chart is as shown in the figure 1.1 below.

Survey studies as well as Experimental measurement will be conducted to collect data's used to estimate the carbon saving of mirt midija and also to calculate the thermal performance of the improved mirt midija/stove, and the following methods are used:

Figure5.1 map of jimma zone

5.2 Method of Data Analysis

Interviews will be conducted with users and non-users of the Improved Cook Stove. Improved Cook Stoves users to be interviewed will be sampled out of a list of households who uses an Improved Cook Stove at household level. Only households that had been using the Improved Cook Stove for at least two months and lived close to the road network will be considered.

Additionally, Traditional stove users will be selected randomly in the neighborhood of the selected Improved Cook Stove user households, this approach is chosen in order to understand the difference between the non-Improved Cook Stove and Improved Cook Stove regarding their efficiency and carbon emission capability.

Household size, cooking frequency and urban/rural distribution, which, according to other studies, might influence the stove efficiency of both the non-improved cook stove and improved cook stove will be studied also [15].

Furthermore, Fuel consumption of other biomass fuels besides fuel wood does not show significant differences between both groups. Only fuel wood as the most important fuel was analyzed quantitatively. Charcoal is not used to prepare staple food; it is only used in small quantities for heating beverages in the study area.

5.2.1 Descriptive analysis

In this thesis descriptive data analysis is used in study

The tools used for quantitative data analysis were descriptive statistics such as mean, minimum as well as maximum values, frequency, percentage and standard deviations respectively. In this case any item that could not be captured through quantitative analysis was analyzed qualitatively using triangulations based upon group discussion and interview with adopters, non-adopters, private producers and the concerned officials of mirte stove technology suppliers.

Here Descriptive statistics were used to analyze and assess the responses of adopters and non-adopters of mirt stove regarding impact caused in mitigating the carbon emission by using improved stove in this case mirt stove as well as the way by which further improvements are undertaken to mitigate more carbon emission is also analyzed by using these descriptive data analyses.

Further factors such as type of fuel energy used, condition of the stove, number of Injera backed at a time, number of Injera baking session per week are also assessed to analyze their effect on the performance of mirt stove.

5.2.2 Definition of variables and working hypothesis.

Within this topic of assessing the impact of using mirt stove the main task is to analyze the effect of mirt stove in reducing (mitigating) carbon emission within the specified study area.

Independent and dependent variables of the hypothesis

1. **Independent variables;** Selected independent variable; the potential variable which supposed to be considered to examine the impact of mirt stove are explained below;
2. **House hold categories**; it is an independent variable which mainly shows whether the user is located in urban or rural areas. This variable also helps to analyze the distribution and adoption of mirt stove in both locations.
3. **Occupation of the house hold**; this is a variable which helps to analyze the occupational status of the user and non-user of the improved cook stove (mirt stove), and also the

information on occupational status helps to understand (analyze) the effect of occupational status in using or adopting mirt stove.

4. **Age of the women**; An independent-sample test which helps to conduct or to test if there was significant difference in the mean age of adopters and non- adopters of mirt stove.
5. **Family size of a house hold;** a variable which helps to understand the mean family size of the sample house holds for adopters and non-adopters, which incase gives information on the relation between the house hold size and fuel consumption.

Dependent variable;

Selected dependent variables which are the main factors in assessing the impact of improved cook stove (mirt stove) in mitigating carbon emission will be discussed in detail. And also detail descriptive data analysis of these dependent variables are presented within statistical data analysis table

1. **Households stratified by stove type**; it is a basic variable which gives information whether the household is an adopter of mirt stove or not, on the survey questioners it represented by 'user' if the house hold adopts the technology and 'non-user' if non user otherwise.
2. **Condition of the improved stove**; it is dependent variable which is used to investigate or analyze the current condition of the stove, in which the information on the condition of the stove also helps to analyze the performance or life span of the stove.
3. **Family size of a house hold**; a variable which helps to understand the mean family size of the sample household for adopters and non-adopters, which incase gives information on the relation of fuel wood consumption with the family size.
4. **Injera baking session;** this dependent variable also helps to investigate the frequency of Injera baking sessions per week for both mirt stove users and non-users. The information on Injera baking sessions per week also helps in analyzing the fuel consumption rate stratified by stove type.
5. **Main source of energy for Injera baking;** it is a variable used in assessing the type of fuel used for Injera baking which incase gives general information about the main energy source(fuel) used in Injera baking process within the study area.

So the following sample questionnaire format is prepared.

1. Characteristics of questionnaires' study households stratified by stove type.

Table5.1 characteristic of questionnaires study households stratified by stove type

Characteristics of house hold	No improved cook stove users	Improved cook stove users	P value of difference
House hold size mean/Standard deviation			
No of cook session per week. Mean/SD			

2. Characteristics of questionaries' for age of the women and household category

Table 5.2 characteristic questionaries' for household category and age of women

Characteristics	Mirt stove users	Non-user	p-value of difference
Age of women(mean/SD)			
Town/rural			

3. Biomass fuel use beside fuelwood stratified by stove type

Table 5.3 Biomass fuel use beside fuelwood stratified by stove type

Biofuel beside fuel wood	ALL	Non ICS user	ICS	p-value difference
charcoal				
Crop residue				
bamboo				

Here the questionnaire was developed according to the factors that likely influence fuel consumption and subsequently tested in the field. Most questions were closed-ended [16,17,18]. Data collection was carried out by interviews will be conducted personally by the first author. The questionnaire contained a large list of questions related to fuelwood use cooking habits and the socioeconomic situation of households.

Parameters that were evaluated in this paper are listed in the following Table.

Table 5.4 relevant parameters assessed in the field survey

parameter	**unit**	**Way of measurement**
Type of fuelwood (tree species)		Identified by interviewer
ICS user	Yes/no	Direct question
HHn: household size	persons	Direct question
Type of fuelwood	tree species	Identified by interviewer
Other type of biomass fuel	kind	Direct question
fd: daily fuel consumption without cooking.	kg wood	Piled by interviewee, weighed (digital scale, 0.01 kg accuracy)
fi: Fuel consumption for one cooking session	kg wood	Piled by interviewee, weighed (digital scale, 0.01 kg accuracy)
tw: Frequency of cooking	Times per week	Direct question

5.3 Result and discussion

Within this chapter of result and discussion the result for survey data will be analyzed in detail. Additionally, result and discussion of the impact assessment on mitigation of carbon emission in the study area are discussed.

For better understanding of the study area the household category, house hold size and age of women are also discussed for both mirt stove user and non-users. To understand the existing relationship of household characteristics with respect to the user and non-user of mirt stove the descriptive analysis is summarized for different characteristics and discussed under different sub headings.

Thus the influences of different cook stove information and situational factors on the performance of mirt stove are also discussed consecutively. The description on the survey data was made using mean, standard deviation as well as p-value difference respectively.

5.3.1 Descriptive result

During the survey assessment total of 150 questionaries' are distributed within the specified area within which the study is undertaken, during the survey process respondents were selected randomly by considering the demographic area on which the survey data was taken including both town and rural regions.

After the data was taken, from total of 150 questionaries' 52 was filled by improved stove (mirt stove) user and the rest of the data's (98 questionaries') are filled by non-users (those who doesn't use mirt stove, relay on traditional cook stoves or three stone fire for Injera backing).

1. **Characteristics of questionnaires' study households stratified by stove type.**

House hold size and number of Injera baking sessions per week are considered in influencing stove efficiency, in this case depending on the values from data the household size for mirt stove users are slightly higher than that of the house hold size for mirt stove non users with the p-value difference of 0.32 from table 1.

And also the data with respect to the number of Injera baking sessions per week indicates that the house hold with larger family size uses mirt stove frequently with respect to the household with smaller family in case the data shows that frequent usage of mirt stove have a greater or positive impact in reducing carbon emission.

Table 5.5 study household stratified by stove type

Characteristics	Mirt stove user(54)	Non-users(96)	p-value difference

	Mean	SD	Mean	SD	
House hold size	6.14	1.83	5.09	1.93	0.32
No of Injera session per week	2.8	1.2	2.6	1.3	0.24

2. Biomass fuel use beside fuel wood for stratified stove type.

Fuel consumption of other biomass fuel beside fuelwood does not show significant difference between both users and non-users of mirt stove. Only fuelwood as the most important fuel was analyzed quantitatively.

Table 5.6 biomass fuel use stratified by stove type

Biofuel beside fuel wood	All(n = 150)	Non adopters (96)	Adopters (54)	p-value difference
Coffe husk	50 (33%)	15 (15%)	35 (67%)	0.75
Crop residue and plant leaf	30 (20%)	20 (20%)	10 (19%)	0.48
Animal waste	10 (6%)	6 (6.25%)	4 (7%)	0.30

2. Biomass fuelwood consumption per yearly basis.

Table 5.7 biomass consumption per year

	Non-mirt stove users (Kg fuelwood per year)	Mirt stove users (kg fuelwood per year)	Fuelwood saving

Injera baking	375(SD 134.3)	220 (SD 106)	155kg
Non Injera baking	452(SD 216)	432 (SD 226)	20kg
Total baking	727	652	175kg
Total annual fuelwood savings per mirt stove user with House hold size of 5.09, SD 1.93		890.75kg	

5.3.2 Side effects leading to fuelwood reduction

When using an improved Injera baking stove (mirt stove); different side effects can positively contribute to save fuelwood. These side effects could only be partly integrated into the fuelwood saving calculations, but might offer more potential for in depth analysis. The factors that were analyzed include the preparation of non- Injera food on the chimney and the use of biomass derived from sources other than wood as fuel.

5.4 Impact on carbon balance

According to GIZ and world vision report [source; Fuel efficient stoves for Ethiopia Program of Activities CPA 001]; mirt stove distribution to households was conducted in cooperation with woreda offices of the ministry of agriculture within jimma zone, these report also states that total of 10,084 mirt stoves were disseminated within the study area. Hereby the above total number of disseminated mirt stove doesn't include stoves produced and disseminated by local manufacturers.

Generally, the probable impact of fuel savings by using ICS on carbon stocks in the study area was evaluated by estimating total carbon savings achieved by all of the improved cook stove (mirt stove) disseminated, corrected by considering the sources of fuel wood and fuelwood species according to the result of the interviews. In this way, the fact that only a part of fuelwood stems from unsustainable sources was taken into account.

5.5 Fuel wood saving due to ICS introduction

According to other fuel saving studies [15,52 - 54], Injera baking accounts for between 40% and 65% of the entire household cooking fuel consumption in Ethiopia. Depending on the survey data and studies mentioned above the annual fuelwood savings of mirt stove per house hold is estimated to be 890kg. Within this data there is a consideration that there is a significance difference between the survey data from the study area and the above mentioned study data. This is due to the fact that households which uses mirt stove were on average slightly smaller than non-user's households however the output is not significantly influence the result.

From the survey data I also found that mirt stove users consume less firewood for cooking purpose other than Injera baking. This could be explained by the fact that while using mirt stove users also prepare sauces or beverages in pots that are placed on the chimney side. Furthermore, the remaining thermal energy of the mirt stove after the Injera preparation is often used to prepare a specific breakfast food, roasting different grain, and consisting of dried Injera (dirkosh).

Generally, test result for the difference of used fuelwood for Injera cooking between non-mirt stove users and mirt stove users are significant depending on the output from test of the **Mann-whitney U test** with P value difference of 0.000 which is 96%. The **mann whitney U test** confirms that mirt stove users consumed less fuelwood per Injera session and person compared to non-mirt stove users

5.6 Impact on carbon balance.

The result from the empirical study shows that each mirt stove in use leads to an average fuelwood saving of 890.75 kg per year table.

By assuming net calorific value of 18MJ/kg [from analytical analysis on chapter 4] and emission factor of 112 of CO_2 per MJ of fuel wood [IPCC] which is corresponds to 2.145tons of CO_2 per mirt stove within a year. Hereby the consideration has been taken when analyzing final impact of mirt stove on carbon saving and that is extent to which fuelwood sources are renewable, i.e. if there will be regrowth of the fuel wood extracted or not. Depending on the result from the survey data estimated share of non-renewable biomass is estimated to be 50%.

Here the calculation on carbon balance was based on IPCC (intergovernmental panel on climate change) default net calorific values, emission factors and carbon storage in forest around the study area.

$$E = fuelwoodsaved\ \ x\ \ fNRB\ x\ NCV\ x\ EF$$

Where;

E, emission

$fNRB, fraction\ of\ non\ renewable\ biomass$;

$NCV, net\ calorific\ value\ at\ dry\ basis$

$EF, default\ emmission\ factor\ (per\ unit\ of\ energy)$

Depending on the result from the survey data shown on table2; from total households of 150 for both users of mirt stove and non-users of mirt stove coffee husk accounts 33%, crop residue and plant leaf 20% and animal waste accounts 6%, while fuelwood still dominates as a major source of energy with a percentage of 96% according to the result from the survey.

According to jimma zone the forest coverage is not much based on observation during survey study. But it has been found that the fuel wood users both manage to buy or collect the fuelwood.

Here different species of fuelwood is used but eucalyptus galipots is the common fuelwood that is used as a source of energy within the study area.

So, by considering the annual fuel saving gained by using mirt stove which is 890.75kg per stove, total of 10,816 tons of CO_2 is saved annually and in terms of pure carbon the saving will be approximated to be 2950 tons of carbon annually. The calculation is done by considering that 80% of the disseminated stoves are fully functional during their life span.

Generally, fuelwood collection for cooking, baking or as a source of income purpose represents a major driver of forest degradation. So the distribution of improved cook stoves has a positive impact on reducing the rate of forest degradation which is probably helps in mitigating carbon emission within the study area or other forest areas.

Chapter 6. Design modification done on mirt stove.

6.1 Introduction

Due to that the stove performance have vary with the design modification done on the stove, because of these modeling the geometry of the existing stove is important to analyze the performance and heat transfer history above its fuel bade by using ANSYS Fluent computational software which is very essential for design of new geometry. As its mentioned earlier on the chapter 3 of these research the other key objective is to design and model new geometry for mirt stove which is more efficient and reliable in utilization of energy.

To enhance better stove design or geometry three consecutive test or performance test was done by modeling and simulating the modified geometry or newly designed concept of the stove using Fluent to find out the best modified stove type with good temperature distribution and performance, also by using the numerical output from the software such as heat flux, temperature, mass flow rate, velocity magnitude of the newly designed stove will be compared and the one with better output will be analyzed. In general parameters related to heat transfer efficiency is compared with each other and also compared with output result of existing cook stove which is bench mark for this study.

In this chapter different design concept for mirt stove is modeled by solid work and Fluent. And their geometry and performance is compared with the existing one which is mirt stove.

6.2 Methodology used and result obtained.

The basic work on design modification was done by modeling the geometry on solid works and further CFD analysis was done on Ansys Fluent.

The following approaches are taken during modeling the geometry.

1. Shifting the position of the fuel inlet towards the left or right side so that there will be increased retention time for the flue gas before it leaves the combustion chamber through the chimney outlet.
2. Changing shapes of the geometry to acquire high flame velocity so that convective heat transfer rate to pan/mitad bottom is increased.

3. Increasing the chimney height to improve the draft so that the amount of air entering the combustion chamber will be higher which incase improves the combustion efficiency of the stove.
4. Providing additional air inlet holes on both sides of the combustion chamber to get sufficient air flow rate with in the stove to increase burn rate and decreases emission caused by incomplete combustion
5. Height or length of stove from ground is kept as it is because increasing the height of chamber will result in decrease or reduced convective and radiative heat transfer to the plate/mitad.

6.3 CFD simulation result

During the simulation process and in analyzing the output result fluent software is used. The main objective or focus of the work done on Fluent Ansys is to analyze the heat transfer of the stove/mirt stove for different modified design. Within the simulation process the boundary condition used is similar to the boundary condition used in analyzing the base line mirt stove which was discussed in detail in section/chapter 3 (input, output, and wall boundary conditions, the user defined thermal property of clay, concreate and properties of wood volatile are selected from fluent data base). Governing equation used and solution methods are all the same.

By the completion of all the test runs in Fluent, several key performance indicators were studied to understand the heat transfer characteristics and trends for each configuration. To understand results we study temperature based results and velocity results in graphical mode and also compares their numerical values.

6.3.1 Definition of parameters`

FLUENT output Parameters used to compare the performance characteristics of biomass cook stove geometry are; heat transferred to the pot (heat transfer at the outlet), heat transfer coefficient, velocity and the energy output of the stove. Thermal efficiency of different geometries is computed to compare their performance with each other.

Thermal efficiency ($= {Q_{utilized}}/{Energy_{in\ fuel}}\ x\ 100$)

Where;

1. $Q_{utilized}$ Heat utilized will be the heat transferred to the pot bottom. (From fluent output let assume heat transfer rate on the outlet is heat utilized by the system).
2. $Energy_{in\ fuel}$; Energy consumed is mass of dry fuel multiplied by heating value. (Which is calculated in chapter four of this paper = 3913W)

Table 6.3 list of newly designed model of mirt stove.

Models	**Geometrical data**	**Input variable**		**Fluid property**	
Mirt stove 	Solid body thickness = 60cm Solid body Height = 0.26m Solid body with chimney height = 0.29m Solid body Outer dia = 0.35m Pan diameter = 0.30m	Inlet	velocity 0.55m/s Temperature 295k Internal emissivity 0.95	Clay	ρ = 1460kg/m3 Cp= 880j/kg.k K= 1.3w/mk
		Outlet	Outflow with back flow temperature of 293k	concreate	ρ = 1400kg/m3 Cp= 800j/kg.k K= 0.98w/mk
		Wall	No slip Stationary wall External emissivity 0.75		
Model 1 	Solid body thickness = 60cm Solid body Height = 0.26m Solid body with chimney height	Inlet	velocity 0.55m/s Temperature 295k Internal emissivity	Clay	ρ = 1460kg/m3 Cp= 880j/kg.k K= 1.3w/mk

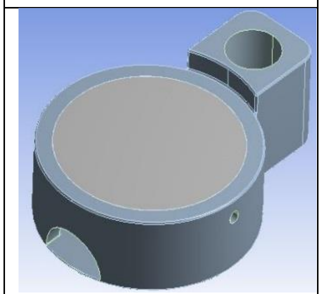
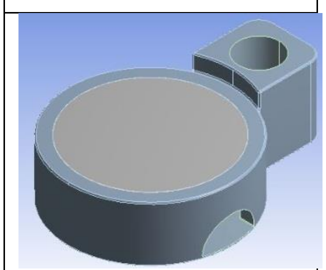
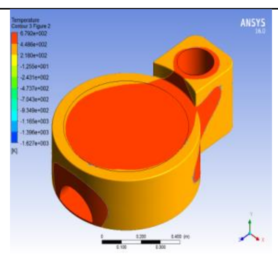
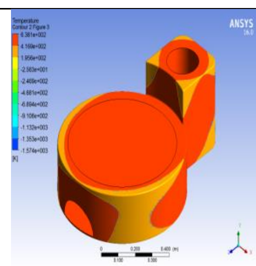
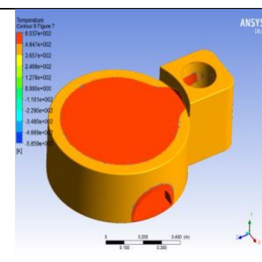
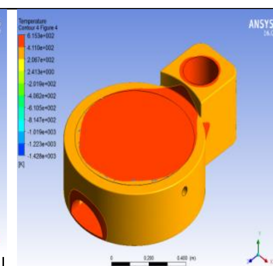
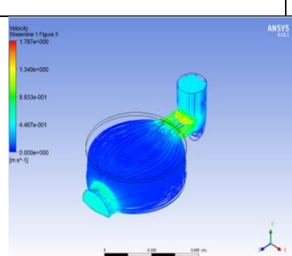
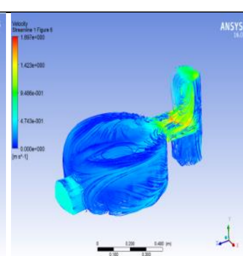
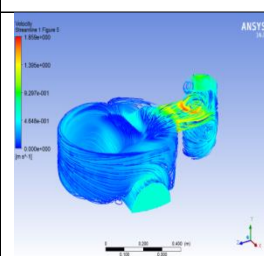
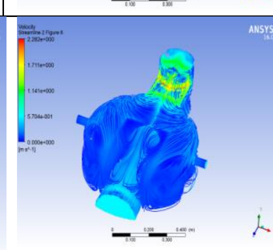
	= 0.32m Solid body Outer dia = 0.35m Pan diameter = 0.30m		0.95		
		Outlet	Outflow with back flow temperature of 293k	Concre ate	ρ = 1400kg/m3 Cp= 800j/kg.k K= 0.98w/mk
		Wall	No slip Stationary wall External emissivity 0.75		
Model 2 	Solid body thickness = 60cm Solid body Height = 0.26m Solid body with chimney height = 0.29m Solid body Outer dia = 0.35m Pan diameter = 0.30m Two holes each with 0.025m	Inlet	velocity 0.55m/s	Clay	ρ = 1460kg/m3 Cp= 880j/kg.k K= 1.3w/mk
			Temperature 295k		
			Internal emissivity 0.95		
		Outer	Outflow with back flow temperature of 293k		
		Wall	No slip Stationary wall External emissivity 0.75	Concre ate	ρ = 1400kg/m3 Cp= 800j/kg.k K= 0.98w/mk
		Smaller holes input	Velocity 0.66, temperature 300k		
Model 3 	Solid body thickness = 60cm Solid body Height = 0.26m Solid body with chimney height = 0.29m Solid body Outer dia = 0.35m Pan diameter = 0.30m Inlet at the side. With dia = 0.115m	Input	velocity 0.55m/s	Clay	ρ = 1460kg/m3 Cp= 880j/kg.k K= 1.3w/mk
			Temperature 295k		
			Internal emissivity 0.95		
		Outer	Outflow with back flow temperature of 293k	Concre ate	ρ = 1400kg/m3 Cp= 800j/kg.k K= 0.98w/mk
		Wall	No slip Stationary wall External emissivity 0.7		

Table 6.4 stove performance vary with stratified stove design mode

CFD output graph s	Contour of total Temperature				
	Contour of velocity Magnitude				

CFD output values	Temperature	pan	420K	430K	450K	480K
		wall	342K	360K	320	355K
	Velocity outlet		0.65m/s	0.56m/s	0.522m/s	0.61m/s
	Heat transfer rate Q	inlet	3805.49W	3945.4W	4207.3W	3903.4W
		pan	2627.47W	2870.5W	2990.4W	2722.4W
	Radiation h6eat transfer	inlet	21W	27W	35W	31W
		wall	26W	36W	47W	41W
	Heat,transfer coefficient		3.45W/m^2.k	4.45W/ m^2.k	7.89W/ m^2.k	6.78 W/ m^2.k
Computed values	Thermal Efficiency $\eta = \frac{Q_{utilized}}{energy_{in\ fuel}}$		34%	43.5%	46.7%	36.5%

The CFD analysis of biomass mirt stove with different design model shows how the stove performance changes with different design model. Depending on the CFD simulation result shown above and numerical values the more efficient stove (**model 3**) is selected, because from the model it is clearly shown that the contour of temperature distribution and numerical results obtained from the CFD analysis, model 3 shows that there is uniform temperature distribution across the domain and high heat transfer rate compared to other designed model as well as the existing one.

And also the temperature distribution on the pan is higher than other designed models as well as the existing one. The outlet velocity of **model 3** (selected model) through the chimney is at optimum condition with respect to other designed models as well as the existing one, which incase results with increased combustion efficiency of the combustion chamber and increased convective heat transfer across the domain.

CHAPTER 7. RESULT AND DISCUSSION

7.1 Introduction

As mentioned earlier, one of the basic objectives of this research is designing modified mirt stove for efficient and effective utilization of energy, so heat transfer and fluid flow simulation on CFD fluent assists the development of a simple model which can be used to predict the performance of a given stove.

Different design modifications were done and investigated to optimize the performance of the stove. Through this the existing mirt stove performance was also investigated by using CFD fluent and also the performance analysis is done by conducting field experiment which is controlled cooking test (CCT). And finally the result obtained from the existing mirt stove was serving as a reference for comparing the performance of the modified design.

Through this process each designed models are undergoes through all simulation procedures; the performance evaluation is performed by using the output results and computed values from these output results.

7.2 Modification made and CFD results.

To improve the performance and efficiency of mirt stove the following design modifications are made accordingly;

By keeping the thickness, height, diameter the same as the existing stove, the fuel inlet is diverted towards the side of the stove with an inlet diameter of 115mm.

Thus increased fuel window increases the amount of air interring the combustion chamber

Diameter of fuel window = 115mm

This design modification is done on the position of the fuel results in decreased smoke due to incomplete combustion produced when starting the fire as a result of more air retention time within the combustion chamber

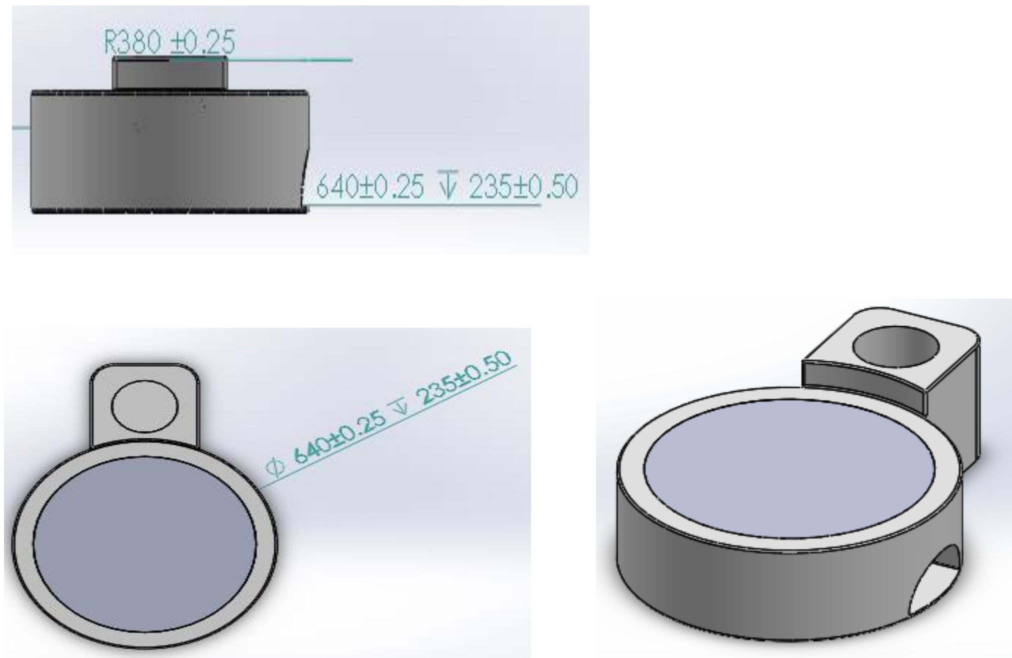
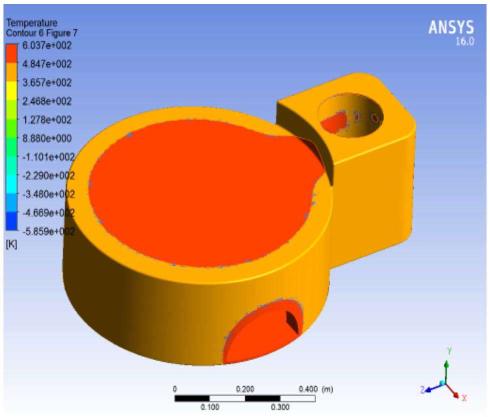
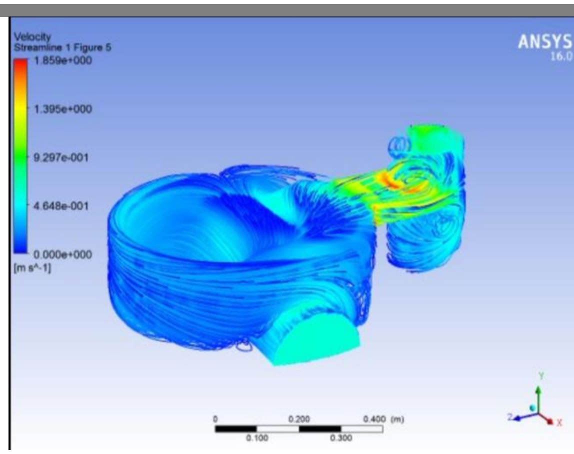


Figure7.1 view of newly designed mirt stove.

7.3 Graphical display and numerical values of newly designed models.





Contour of total temperature (K)

contour of velocity magnitude (m/s)

According to the result shown from the temperature contour the stove has better temperature distribution over the pan domain and there is optimum temperature distribution over the solid domain. The temperature value that reaches the pan domain is higher and standard for the baking process (450k) than that of the existing mirt stove and other tried design models.

The heated air velocity through the combustion chamber is at optimum condition (0.522) relatively with respect to velocity distribution with the existing mirt stove and for newly tried design models, the velocity condition for the selected design model mainly helps in maintaining increased combustion efficiency because of maximized retention time of air within the chamber by allowing more air flow rate through the chamber.

Area-Weighted Average Velocity Magnitude	(m/s)
inlet	0.5
outlet	0.54014673
Net	0.52218827

The condition often leads to more turbulence which improves heat transfer efficiency compared against laminar flow behavior; this condition mainly arises from the position of the inlet (on the newly designed model), which is at the side of the stove.

Also the increased fuel entrance on the solid domain resulted in higher air flow rate in to the combustion chamber, which mainly resulted in higher combustion efficiency by decreasing the condition for incomplete combustion of the fuel.

Generally the heat transfer rate across the domain of the selected design model is greater that other tried design models as well as the existing one, therefore heat transfer efficiency of the new designed model will be calculated and presented as follows.

By assuming the heat transfer rate at the pan as heat utilized in the system

Thermal efficiency ($= {}^{Q_{utilized}}\!\big/_{Energy_{in\ fuel}}\ x\ 100$)

Where;

1. $Q_{utilized}$ Heat utilized will be the heat transferred to the pot bottom. (From fluent output let assume heat transfer rate on the outlet is heat utilized by the system).
   Heat transfer rate over pan, 2990W.
2. By considering heat lost by convection and radiation as 25% of heat utilized the net heat transferred to the pan will be; 2243W

3. $Energy_{in\ fuel}$; Energy consumed is mass of dry fuel multiplied by heating value. (Which is calculated in chapter four of this paper = 4639W)

$$\eta_{th} = \frac{Q_{utilized}}{E_{energy\ in\ fuel}}\ x\ 100$$

$$\eta_{th} = \frac{2243}{4639}\ x\ 100$$

$$= 48.3\%$$

Note. The numerical or the simulation result for the calculation of thermal efficiency does not consider the effect of external factors such as humidity, daily temperature condition and daily wind speed, by considering those mentioned factors the thermal efficiency result acquired from the simulation will decrease by ≤ 4%.

CHAPTER 8. CONCLUSION AND RECOMMENDATION

8.1 Introduction

Energy is one of the most important basic commodities that determine the progress and status as well as the well-being of any society. A country's socio-economy cannot show progressive development unless energy is explored, developed, distributed and utilized in an efficient and appropriate way.

Through this in Ethiopia government and non-governmental organizations are highly participating in designing and production of different efficient and effective biomass cook stoves to hinder the problem with deforestation and health related issues because of an efficient and effective utilization of wood biomass for cooking purpose. And from those stoves mirt stove is one of the improved cook stoves which are mainly used for baking the local Injera.

Based on this experimental, field survey as well as CFD analysis have been employed in this study to investigate the impact of improved mirt stove to mitigate carbon emission as well as to design new modified mirt stove for better utilization of energy depending on the data assessed from the study area.

8.2 Conclusions

- Experimental results indicated that the average specific fuel consumption of the stove is 220g/kg and average Baking time per Injera is recorded as 2.3minutes and also the stove performed slightly better when a centimeter or so of ash was left in the base of the combustion chamber. This meant slightly less air passing up through the grate which seemed to improve combustion and ease of lighting.
- Concerning the field survey data mirt stove has a better performance over three stone stoves. Fuel wood consumed with mirt stove annually per baking session is about 220kg while it is about 375kg with three stones stove. The difference in fuel wood consumption is about 155kg annually; the average number of Injera session per week in the study area which is about 2.8 for mirt stove users depending on the household size of the study area can save 890.5Kg of fuel wood annually. Depending on the data assessed from the study area and depending on the amount of improved cook stove (mirt stove) disseminated total of 10,816 tons of CO_2 is saved annually and in terms of pure carbon the saving will be approximated to be 2950 tons of carbon annually.
- Regarding the design modification done on the stove by increasing the inlet diameter and by changing the position of the inlet towards by the side of the stove the problems with smoke during warming period will be reduced because of an increased air flow through the combustion chamber.
- And finally by using the output value from the CFD fluent analysis the thermal efficiency of the newly designed model is computed and compared with the existing mirt stove and also with other optional design models, and the efficiency of the newly designed model is 48.3% while the efficiency of the existing mirt stove is 34% as depending on the result from simulation.

8.3 Recommendations

Recommendations for further work to enhance more research and improvements done on mirt stove are listed as follows;

- Based on the experimental result; the efficiency for the existing mirt stove was around 25%. So, it is important to investigate the efficiency improvement of the newly designed stove.
- It has been discussed before that the efficiency and the performance of Injera baking stoves mainly relays on the thermal conductivity of the pan material because of that the performance and efficiency of the stove could be increased by using low thermal conductive materials for holding the resisters at the back of the plate, moreover the durability of the pan has to be optimized by using different ceramic materials.
- Further some improvements of the disseminated "Mirt" stove could positively contribute to fuelwood savings. The users often mentioned that the design of "Mirt" stoves is not appropriate for the separately bought clay Mitad. As these clay plates are produced traditionally by hand with unstandardized designs and sold at local markets, the perimeter can vary, leading to gaps between the stove and the clay plate that lessen the efficiency of the stove. Moreover, it seems that using clay plates, thermal energy is used very inefficiently.

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Appendix.1

TEST I

Input parameter and result obtained.

CCT-1 for the SLIM VERSION Wind conditions: no wind

Shaded cells require user input; unshaded cells automatically display outputs Air temperature: **20.8** °C

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

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	3500	f_i	51	f_f	inkib (pot) wt: 650gm; empty bucket wt: 1110gm
Weight of charcoal+container	g			224	c_c	charcoal container wt: 440gm; net dough wt: 1600gm
Weight of Pot # 1 with cooked food	g			8270	$P1_f$	first pouring of dough: 9:53a.m.
Weight of Pot # 2 with cooked food	g				$P2_f$	bucket with remaining dough wt: 1720gm
Weight of Pot # 3 with cooked food	g				$P3_f$	total number of injera baked: 29
Weight of Pot # 4 with cooked food	g				$P4_f$	remaining charcoal with container : 710+780+760gm
Time	min		t_i	81	t_f	this test was conducted on 12.05.2011

CALCULATIONS			Formula
Total weight of food cooked	g	7816	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$
Weight of char remaining	g	152	$\Delta c_c = k - c_c$
Equivalent dry wood consumed	g	1736	$f_d = (f_f - f_i)*(1-(1.12*m)) - 1.5*\Delta c_c$

CALCULATIONS			Formula
Specific fuel consumption	g/kg	222	$SC = \frac{f_d}{W_f} * 1000$
Total cooking time	min	81	$\Delta t = t_f - t_i$

TEST II

Input parameter for test 2 and result obtained

CCT-2 for the slim version Wind conditions: no wind

Shaded cells require user input; unshaded cells automatically display outputs Air temperature **21.5** ºC

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

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	3264	f_i	47	f_f	inkib (pot) wt: 650gm; empty bucket wt: 1110gm
Weight of charcoal+container	g			350	c_c	charcoal container wt: 440gm; net dough wt: 1520gm
Weight of Pot # 1 with cooked food	g			8490	$P1_f$	first pouring of dough: 8:53a.m.
Weight of Pot # 2 with cooked food	g				$P2_f$	bucket with remaining dough wt: 1620gm
Weight of Pot # 3 with cooked food	g				$P3_f$	total number of injera baked: 26
Weight of Pot # 4 with cooked food	g				$P4_f$	remaining charcoal with container : 710+780+760gm
Time	min		t_i	98	t_f	this test was conducted on 13.05.2011

CALCULATIONS			Formula	CALCULATIONS			Formula
Total weight of food cooked	g	8024	$W_f = \sum_{j=1}^{4}(Pj_f - Pj)$	Specific fuel consumption	g/kg	202	$SC = \frac{f_d}{W_f} * 1000$
Weight of char remaining	g	237	$\Delta c_c = k - c_c$	Total cooking time	min	98	$\Delta t = t_f - t_i$
Equivalent dry wood consumed	g	1619	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$				

TEST III

Input parameter and result obtained

CCT-3 for the — Wind conditions: no wind

Shaded cells require user input; unshaded cells automatically display outputs — Air temperature **21.9** °C

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

MEASUREMENTS	Units	Initial measurements data	Initial measurements label	Final measurements data	Final measurements label	Comments about cooking process (smokiness, ease of use, etc)
Weight of wood used for cooking	g	4188	f_i	61	f_f	inkib (pot) wt: 650gm; empty bucket wt: 1110gm
Weight of charcoal+container	g			379	c_c	charcoal container wt: 440gm; net dough wt: 1855gm
Weight of Pot # 1 with cooked food	g			8261	$P1_f$	first pouring of dough: 10:53a.m.
Weight of Pot # 2 with cooked food	g				$P2_f$	bucket with remaining dough wt: 1820gm
Weight of Pot # 3 with cooked food	g				$P3_f$	total number of injera baked: 35
Weight of Pot # 4 with cooked food	g				$P4_f$	remaining charcoal with container : 710+780+760gm
Time	min		t_i	107	t_f	this test was conducted on 16.05.2011

CALCULATIONS			Formula
Total weight of food cooked	g	7807	$W_f = \sum_{j=1}^{4} (Pj_f - Pj)$
Weight of char remaining	g	257	$\Delta c_c = k - c_c$
Equivalent dry wood consumed	g	1855	$f_d = (f_f - f_i) * (1 - (1.12 * m)) - 1.5 * \Delta c_c$
Specific fuel consumption	g/kg	238	$SC = \frac{f_d}{W_f} * 1000$
Total cooking time	min	107	$\Delta t = t_f - t_i$

Final result obtained

1. CCT results: Stove 1	units	Test 1	Test 2	Test 3	Mean	St Dev
Total weight of food cooked	g	7,816	8,024	7,807	7,882	123
Weight of char remaining	g	152	237	257	215	56
Equivalent dry wood consumed	g	1,736	1,619	1,855	1,737	118
Specific fuel consumption	g/kg	222	202	238	220	18
Total cooking time	min	81	98	107	95	13

Appendix.2

Jimma Ethiopia

General household questioner stratified by stove type

Questioner no. ________________ date. ____________________

Supervisors name. ______________ interviewers name. _______________

Name of the respondent. __________

Kebale. ______________ zone. ______________

House hold categories;

A. *Urban _________ Rural ____________*
B. *Poor ___________ medium poor _____________ better off.*

Section A. personal information.

1.who is the head of the house hold?

a. husband b. self c. others specify

2. what is the occupation of the house hold?

a. farming salaried/ employed c. self-employed/ business man

d. part time employed e. other specify

3. what is your age approximately?

4. how many people regularly live and eat in the house hold? Specify numbers

a. older people (>64 years) ________

b. adults (> 16 years) ____________

c. children's (< 15 years) ____________

d. total number of households ________

section B. cook stove information.

5. what kind of stove is used for Injera baking in the house hold

a. non improved cook stove/ three stone b. improved cook stove/ mirt stove

c. other/ specify.

6. condition of the improved stove?

a. good condition b. cracks on the body c. cracks on the liner

d. broken plate rest. E. others specify

7. for how long have you had these stoves (in months or years). Specify.

9. how often do you usually bake Injera per week?

a. once a week b. twice a week c. three times a week

d. other (specify)

10. how many Injera did you bake at a time (average)? _________________

11. is there any application that you use the Injera baking stove for other appliances?

a. yes (how many times a week) specify

b. No

12. Which type of fuel is the main source of energy for cooking and heating for the family?

a. wood b. animal waste c. crop residuals and plant leaves charcoal

d. kerosene

13. Which one is the main source of energy for Injera baking?

a. fire wood b. animal waste d. crop residue and plant leaves

d. charcoal

14. if your answer for question no 10 is fire wood: do you by, collect it or both.

15. what advantage do you see in using an improved stove? (several answers are possible)

a. fuel saving b. cook fast c. reduced smoke

d. clean kitchen e. save money f. less burns, accidents.

16. Did you use the improved stove for any other purpose other than baking?

a. yes b. No

17. if yes for what type of purpose did you use it?

a. for baking kita or brade b. for roasting grain c. other (specify)

18. did you use the chimney side for any other purpose other than baking?

a. yes b. No

19. if yes for what type of purpose did you use it?

a. coffee boiling b. sauce cooking c. other (specify)

20. do you see any disadvantage of an improved cook stove? Yes, or No

If yes,

a. not possible to sit around b. takes more time to bake Injera

c. needs maintenance e. other(specify)

21. do you have any suggestion if some modification is needed on the existing improved stove?

____